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ORIGINAL ARTICLES.

On the Spilitic Rocks.

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THE problem of the spilitic rocks is one of the most interesting in petrographical science. The extreme deficiency of potash, as also the peculiar combination of a large amount of femic minerals containing a considerable amount of CaO and a plagioclase rich in albite, render the rocks unique in the petrographical systems. Furthermore, the appearance of associated rock-members extremely poor in femic minerals, and composed almost entirely of albite or albite and quartz, adds a new element of interest. Specially worthy of mention in this connection are the keratophyres distinguished by an abnormal amount of magnetite, the so-called magnetite-keratophyres or magnetite-syenite-porphyries, known from the Swedish Lapland ore district, Australia, and other places. The interpretation of these rocks does not constitute an isolated question but is connected with the solution of the whole spilite problem.

In this paper one side of the spilite problem will be discussed, namely the chemical and petrographical relations of the spilite group proper, and the relations of spilites to other magmatic rocks of equal acidity. The settlement of these questions, moreover, is a necessary condition for the discussion of the cause of differentiation.

Historical Notes.

The problem of the spilites became prominent in petrographical literature through the papers of the British authors, Sir J. J. H. Teall,[1] E. B. Bailey and G. W. Grabham,[2] Sir J. S. Flett and H.

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[1] *Mem. Geol. Surv.*, 1899, p. 85.
[2] Geol. Mag., 1909, p. 250.

Dewey.[1] Somewhat earlier Termier had published a discussion of the rocks from Mt. Pelvoux, which bore upon the subject.[2] The well-known opinion of the British authors was that the spilitic rocks, at least in those cases where they are rich in decomposition products, were altered by an autometamorphic change, soda and carbon dioxide being retained in solution during the solidification of the magma, after which they acted upon the minerals of the rocks. In this way a decomposition of the calcic minerals would come about, the CaO-content at the same time being fixed in calcite and epidote or possibly carried away. A high soda-content, however, was considered to have existed in the original magma, and in some cases, where the amount of secondary alteration products is small, an original albitic felspar was admitted.

By Flett and Dewey the spilitic greenstones were included with the salic, soda-rich and basic rocks occurring together with them in a special petrographical group, *the spilitic suite*, which was compared with the two principal groups of magmatic rocks, the Pacific and Atlantic.

Owing to the work of the British authors mentioned, the term "spilite" obtained the significance at present usual. Originally the sense of this term was chiefly textural, and it referred to the dense, vesicular, and non-porphyritic consistency of the respective greenstone rocks. By the above-mentioned and later authors the term was used in a chemical-petrographical sense as designating femic rocks with a high soda-content and containing an acid plagioclase as the dominating felspar. The term will be applied in this sense also in this paper. A greatly decomposed stage of the rocks also is considered to be implied by the term, but this is not general or necessary for the rocks belonging to the spilitic group.

According to Termier, the high alkali-content and the low amount of CaO in the rocks described by him are due to the action of percolating water which had previously passed through alkali-rich rocks. A certain influence in a chemical respect from the wall-rock during the alteration process is rendered likely by the dikes described by Termier, which traverse Or-richer granites. In these dikes the alteration has been accompanied by an increase in K_2O, while in the melaphyres, interbedded with schists, the content of this oxide is low. An alteration of this kind, however, must be superficial and can hardly attain other than local significance.

A very instructive example of spilitic rocks was described in 1913 and 1915 by W. N. Benson[3] from New South Wales, Australia. These rocks, in contrast to most occurrences of spilites, are very little decomposed, and Benson fails to find any ground for the assumption of mineralogical or chemical changes in the rocks and their minerals.

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[1] Geol. Mag., 1911, pp. 202 and 241.

[2] *Bull. Soc. Geol. Fr.*, vol. xxvi, 1898, p. 165.

[3] Geol. Mag., 1913, p. 17; *Linn. Soc. of New South Wales*, vols. xxxviii and xxxix.

In 1907–10 the present writer, together with his colleague, Dr. N. Zenzén, was working on the Archaean rocks of the Kiruna district, and there came into contact with the spilitic greenstone formation of the ore-bearing rock series. Our assumption as to the greenstones was at first that the albite of the rocks was primary, at least in those cases where secondary alteration products such as epidote, calcite and chlorite were inconsiderable in amount. This opinion, therefore, was put forward in the first sketch of the geology of the district.[1] Further experiences in the field and from a considerable number of slices convinced us that this conception was not correct, but that the whole mineral assemblage of the rocks—albite, uralite and varying amounts of epidote, calcite, and chlorite—must be the result of secondary alterations. The rocks are discussed more explicitly by the writer in his description of the southern part of the Kiruna district.[2] As my argument has been misunderstood by some later authors, it will be referred to at some length. According to the view of the writer, the felspar of the rocks was primarily a more basic plagioclase, probably an andesine or labradorite. This view was taken on account of the textures of the rocks, which resemble those of a diabase or basalt. Furthermore, in rare cases, remains of these felspar mixtures were found, and in a restricted area the rocks had a diabasic composition and were made up of labradorite and uralite, the former being little altered. The alteration process was considered to be the consequence of the metamorphism of the rocks, the anorthite and the pyroxene not being stable under the conditions prevailing at the time. Moreover it was found that the distribution of the epidote could be rather irregular even within small areas, some parts of the rocks being richer in this mineral, others being poorer. This was assumed to be due to a certain mobility of the epidote during the alteration process, on account of which the mineral in question could be assembled in some parts of the greenstones, adjacent parts at the same time being poorer in it. In the former parts albite would have been replaced by epidote ; in the parts poor in epidote, on the other hand, the amount of albite would have increased. When analysing a specimen of the latter kind we should thus obtain an Ab-richer composition than in the former case, and also as compared with the original relations. These mineral exchanges within the rock masses generally would not imply any change in the average composition of the rocks, at least not a change of any considerable importance.

A special problem was presented by the southernmost part of the greenstone-zone (on the mountain Pahtosvaara). In this area minerals rich in CaO were absent. The only CaO-bearing minerals of any importance in the main part of the area are amphibole, for the most part rich in iron, and scapolite, the latter, however, being rather poor in meionite. As everywhere in the district, the scapolite was found to correspond chemically to the felspar of the rocks in which it occurred, no alkalies could have been contributed simultaneously with the scapolitization, the only elements contributed to the rocks in this process being Cl and CO_2. The occurrence of the scapolite, furthermore, is very irregular ; the albitic character and the absence of epidote or other CaO-rich minerals, on the other hand, is general for almost the whole mountain. When assuming an originally basic felspar in the greenstones one must also assume a real alteration of the bulk of the rocks : at least a loss of some amount of their CaO-content must be admitted. On account of the textural relations of the rocks mentioned above, the writer was at this time inclined to assume a hypothesis of this kind, although he did not consider the matter decided. Later experience has convinced him that it is not necessary to assume an originally calcic and later albitized plagioclase in rocks of this kind.

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[1] Hj. Lundbohm, "Sketch of the geology of the Kiruna District" : *Geol. Fören. Förh.*, Bd. xxxii, 1910, p. 751.

[2] *Vetenskapl. och praktiska undersökningar i Lappland, anordnade av Luossavaara-Kiirunavaara Aktebolag*: "Geologie des Kirunagebiets," vol. iv, Stockholm, 1915.

The opinion of the writer was criticized by P. Geijer, who maintained the theory of an autometamorphic or contact-metasomatic alteration of the Kiruna greenstones.[1] Assuming a supply of soda from outside and an earlier anorthite-rich plagioclase in the greenstones, the latter process implies a considerable change in the chemical composition.

The problem of the spilites has subsequently been discussed by A. K. Wells [2] and P. Eskola [3] in two very suggestive papers. Wells points out the independence of the magma of the spilitic suite. As the principal properties of this magma, a marked richness in soda and deficiency in magnesia are mentioned.

The importance of the spilitic problem is fully recognized by Eskola. Like the British authors, he maintains an autometasomatic alteration of the rocks described by him, but he does not accept the idea of an independent spilitic magma. The alteration of the felspar, according to Eskola, is not caused by water solutions rich in sodium carbonate, but by a residuum in the rocks of sodium metasilicate and quartz. Owing to the low eutectic melting-point of these compounds, they are retained in solution after the separation of the other compounds of the magma, and then act upon them. In this way the anorthite-bearing plagioclase is converted into albite, the lime being carried away. As mentioned by Eskola, this process does not necessarily postulate a generation of the active agents by the magma of the altered rock. A contact-metasomatic activity also may be caused in the same manner, if the solutions spread out into adjacent rocks.[1]

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[1] P. Geijer, *Geol. Fören. Förh.*, xxxviii, p. 243 ; and N. Sundius, ibid., 1916, p. 446.

[2] A. K. Wells, Geol. Mag., LIX, 1922, p. 346 ; and LX, 1923, p. 62.

[3] P. Eskola, *Fennia*, xlv, No. 19, 1925.

Summing up the discussion, the principal points bearing upon the spilites are the following : Are the spilites unchanged in a chemical respect, and do the analyses show the correct composition of the corresponding magma, omitting possible gains of water and carbon dioxide bound up in secondary alteration products ? And

Do the spilites belong to a separate suite of rock magmas ?

These and some other questions bearing upon the spilitic rocks will be briefly discussed here, in connection with a review of the chemical properties of the rocks.

GEOLOGICAL AND CHEMICAL RELATIONS OF THE KIRUNA GREENSTONES.

The Kiruna greenstones have many essential properties in common with the British spilites. The bulk of the rocks are lava-flows, in part interbedded with tuffs and breccias. The lavas present extensively the characteristic pillow-structure, developed in most cases along the borders of the flows, though instances are also known of flows composed throughout of pillows. The pillow-structure occurs in albite-rich members of the formation, as well as in uralite-diabases with a calcic felspar or in rocks rich in epidote. Chemically the greater part of the greenstone zone is built up of albite-rich rocks, but rocks rich in anorthite, or in epidote and calcite combined with albite, are also represented. Together with the effusives there are found, in a few instances, dikes or small masses of an intrusive greenstone texturally distinguished from the lavas by a coarser structure. Some of these intrusive rocks contain remains of a basic plagioclase (An_{40}–An_{57}), but in most cases the rock is a saussurite-diabase or an altered greenstone richer in albite. As to the age of these intrusives nothing definite can be said, but they are believed by the writer to belong to the same eruptive series as the effusives.

At the time the Kiruna description was worked up four analyses of the Kiruna greenstones, referred to here as Nos. 1–4 of Table I, were available. One of them (No. 1) represents an effusive diabase with labradorite as the dominant felspar. This rock shows but slight traces of alteration, beyond the change of the former pyroxene into uralite. Nos. 2–3 are true spilitic rocks containing as felspar only pure albite.[1] Both analyses are made on material of dense, effusive rocks. When choosing the material for these two analyses, rocks rich in albite were selected. Rocks of this composition play a great part in the greenstone-formation, but nevertheless the two analysed specimens are not representative of the whole average of the albite-bearing rocks, as in many instances the amount of epidote and calcite, or of secondary amphibole formed at the expense of the felspar, may be considerably greater. The fourth analysis refers to an intrusive greenstone, which forms a small mass on the hill Valkeasiipivaara, to the north of Kiruna. Also of this rock a specimen very poor in epidote was selected. If the opinion of the writer about the mobility of the epidote is correct, an average analysis of a number of specimens from a larger area would give a more anorthitic composition than the specially selected specimens. To prove this, an average sample was taken from the before mentioned intrusive mass at Valkeasiipivaara, in which a considerable range of mineralogical composition occurs. The writer is indebted to Dr. R. Looström, who complied with his request to collect an average sample. All the slices of the separate specimens of the average sample show the same textural relations as, and a similar mineral assemblage to, the specimen analysed before, but the amount of epidote is generally greater. The average analysis was made by the chemist of the Swedish Geological Survey, Dr. A. Bygdén, and is quoted as No. 5 of Table I.

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[1] When this paper was already written I received the work of G. Beskow ("Södra Storfjället im südlichen Lappland": *Sveriges Geol. Undersökn.*, Ser. C, No. 351). The spilitic problem is discussed by him, and he finds the explanation of the alteration of the rocks and their albitic felspar to be due to an outside influence from the water into which the submarine lavas flowed. The new analyses from the Swedish mountain chain are in accordance with those of C. W. Carstens, mentioned later in this paper, and do not agree well with the spilites proper.

TABLE I.

	1	2	3	4	5
SiO_2	49·10	50·76	55·04	50·23	48·55
TiO_2	1·12	1·60	1·15	0·36	1·13
Al_2O_3	15·70	14·57	13·83	14·45	13·50
Fe_2O_3	1·87	4·11	2·19	1·83	3·56
FeO	10·06	10·59	7·39	9·46	10·20
MnO	0·63	0·09	0·20	0·26	0·27
Mgo	6·91	2·86	4·78	10·41	7·37
CaO	10·88	7·54	7·08	5·47	8·58
Na_2O	2·39	5·54	5·90	4·30	2·94
K_2O	0·44	1·04	0·36	1·83	0·32
H_2O	0·45	0·94	0·77	1·72	3·24
P_2O_5	0·07	0·06	0·08	0·04	0·09
CO_2	n.d.	n.d.	1·28	—	—
	99·62	99·70	100·05	100·36	99·75 [2]

From the figures of the two analyses, Nos. 4 and 5, it is evident that the latter is essentially richer in CaO and poorer in Na_2O than the former. This accords with the view expressed by the writer, and is explained by the supposed migration of epidote from the rock of No. 4 and some introduction of soda into it. The higher content of Fe_2O_3 in No. 5 also accords with the assumption of an enrichment in epidote. On the other hand, the different relations between the alkalies in both analyses and the low Al_2O_3-content of No. 5 can not be interpreted by the mineral exchanges mentioned. The result of the comparison of the two analyses, therefore, must be that some change in the analysed spilitic specimen (No. 4) may have occurred, owing to migration of epidote and some contemporaneous gain in soda, but besides this, variations in chemical composition must have taken place originally in the mass.

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[1] According to an analysis of the separated felspar, the formula would be $Or_5Ab_{90}An_5$. As the analysed powder contained some inclusions of hornblende, some part of the CaO must enter into this mineral. The correct formula therefore would lie between 95 and 100 per cent of alkali-felspar.

[2] Add $S = 0·10$, $BaO = 0·03$, $Cr_2O_3 = 0·03$.

In the calculation of the plagioclase of the norm from the two analyses, the formula in No. 4 becomes $Ab_{72}An_{28}$, in No. 5 $Ab_{54}An_{46}$. The latter conforms to the felspar of a diabase or a basalt. However, as inhomogeneities in the chemical composition may have occurred originally in the rock mass, the whole difference between the two felspars cannot be due entirely to later changes, but may to some extent be primary. The average analysis thus does not indicate great chemical changes of the separate parts of the rocks during the mineral alteration processes ; still less likely is it that the bulk compositions of the rocks have been influenced.

CHEMICAL RELATIONS OF THE SPILITES.

A fairly large number of analyses have been published of spilites and more anorthite-rich rocks associated with them. Unfortunately some of them are incomplete, and others are not quite trustworthy. The less suitable being discarded, the collection made by the writer comprises nineteen analyses, namely : three from England,[1] seven from the Nundle and Tamworth districts, New South Wales, Australia,[2] five from the Kiruna district, and four from Karelia, Finland.[3] From the Norwegian mountain chain five analyses of greenstones have been published by C. W. Carstens,[4] the corresponding rocks being characterized as basalts relatively rich in albite, though hardly spilitic in character. All his analyses show an extreme deficiency in potash, but only in one case does the felspar of the norm agree with that of a spilite. In this case, however, the analysed specimen, according to the description, was not homogeneous. On account of this the position of the Norwegian rocks becomes uncertain, and for this reason they will not be considered here.

All the analysed rocks listed above are rich in femic minerals, the amount equalling that of a diabase or being but little less. Only one of the Karelian rocks (the "granophyre" from Kuusniemi) is somewhat more salic, and at the same time it contains a considerable quantity of quartz (17 per cent, the dark minerals at the same time amounting to about 28 per cent). In the other rocks quartz is absent or quite subordinate.

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[1] H. Dewey and J. S. Flett, GEOL. MAG., VIII, 1911, p. 206; Analyses No. I and II, C. I. Gardiner and S. H. Reynolds, op. cit., p. 96.

[2] W. N. Benson, op. cit., Nos. 117, 1,002, 1,021, 145, 1,109, 1,132, 1,130.

[3] P. Eskola, op. cit., pp. 13, 19, 24, and 33.

[4] C. W. Carstens, *Norsk Geol. Tidskrift*, vii, 1924, p. 185.

A review of the collected analyses shows them to vary within rather wide limits, and among the corresponding rocks there are found several which would be and partly are designated by the authors as diabases or basalts, though the felspar still present may in some cases be albitic in character. On the diagram Fig. 1 are plotted the points corresponding to the calculated felspar of the norm.[1] Most of the points are grouped in the vicinity of the plagioclase line between 7 and 40 per cent of An; above the last-mentioned point lies a smaller group comprising five analyses. It seems proper to separate these latter from the former as a group of diabases. The other points would thus represent spilitic rocks in

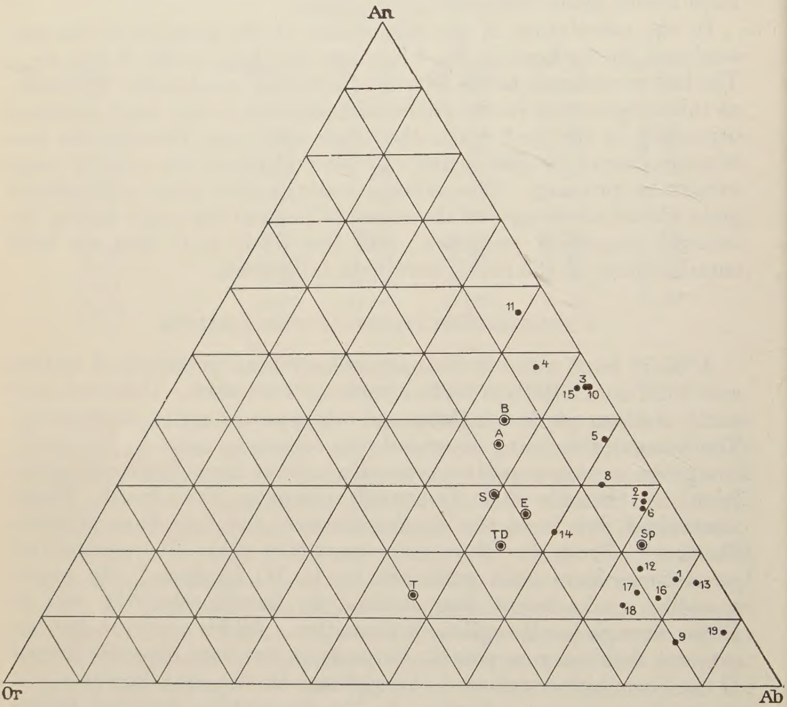

FIG. 1.

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[1] The figures in the diagram refer to the following rocks: 1–3, British spilites; 4–10, Australian spilites and dolerites; 11–15, Kiruna greenstones; and 16–19, Karelian spilites.

the proper sense. Though no definite boundary between the two groups is indicated by the relations in the diagram, yet there is a distance between 30 and 44 per cent of An in which only two dots are situated. An average of the spilitic members as defined above would give the figures quoted below. As a comparison some averages of subalkaline and alkaline intermediate rocks are quoted from Daly. The felspar mixtures of the averages are represented on the diagram by dots with a circle (Sp = spilite, B = basalt, A = andesite, S = augite-syenite, E = essexite, TD = trachydolerite, T = trachyte).

TABLE II.

	Average Spilite.	Basalt.	Andesite.	Augite-Syenite.	Essexite.	Trachy-dolerite.	Trachyte.
SiO_2	51·22	49·06	59·59	51·59	48·64	49·20	60·68
TiO_2	3·32	1·36	0·77	0·61	1·86	1·68	0·38
Al_2O_3	13·66	15·70	17·31	18·77	17·96	16·65	17·74
Fe_2O_3	2·84	5·38	3·33	6·11	4·31	4·76	2·64
FeO	9·20	6·37	3·13	3·26	5·58	5·36	2·62
MnO	0·25	0·31	0·18	0·24	0·19	0·55	0·06
MgO	4·55	6·17	2·75	4·11	4·00	4·43	1·12
CaO	6·89	8·95	5·80	7·35	8·89	7·74	3·09
Na_2O	4·93	3·11	3·58	4·35	4·30	4·54	4·43
K_2O	0·75	1·52	2·04	2·99	2·28	3·19	5·74
H_2O	1·88	1·62	1·26	0·26	1·34	1·30	1·26
P_2O_5	0·29	0·45	0·26	0·36	0·65	0·60	0·24
CO_2	0·94	—	—	—	—	—	—

In the diagram the spilitic rocks, like the diabase rocks combined with them, form a narrow zone along the plagioclase line. When adding to the collection the keratophyric salic rocks, associated with the spilites, the whole distance to the immediate vicinity of the Ab-corner would be filled up. Undeniably the extreme deficiency in potash is a special character of the spilitic series. Of the members of the series the spilites represent a singular rock type. They are separated on the felspar diagram from the ordinary types of alkalic or subalkalic character by an area in which very few magmatic rocks are represented. Such a rock is mugearite, but even this contains a considerably larger amount of Or than the spilites. The spilites thus form a group petrographically different from other rocks. At the diabasic end of the spilitic series the distinction on the felspar diagram from ordinary basalts or diabases becomes more dubious, as many rocks of the latter kind also may show great deficiency in Or. Yet on an average a difference is shown also here.

Besides the deficiency in Or, there are some other features of the chemical constitution, in part pointed out by Wells, that are characteristic of the spilites. These are a relative deficiency in Al_2O_3 and a high content of ferrous iron as also of titanic acid. The first-mentioned quality constitutes the main reason for the acidic composition of the felspar of the rocks, as CaO is not present in small quantities. The deficiency in Al_2O_3 is characteristic of all spilites but is less towards the diabasic end of the series.

The large content of ferrous iron in the spilites is shown by the table of averages when the figures for FeO are compared. At the same time, the amount of MgO is not less than ordinary in rocks of equal richness in femic constituents. The relation of FeO and MgO in the individual analyses is shown by the diagram Fig. 2, in which are plotted the points corresponding to the molecular proportions of (Fe, Mn)O, MgO, and Na_2O, in the rocks. The line drawn from

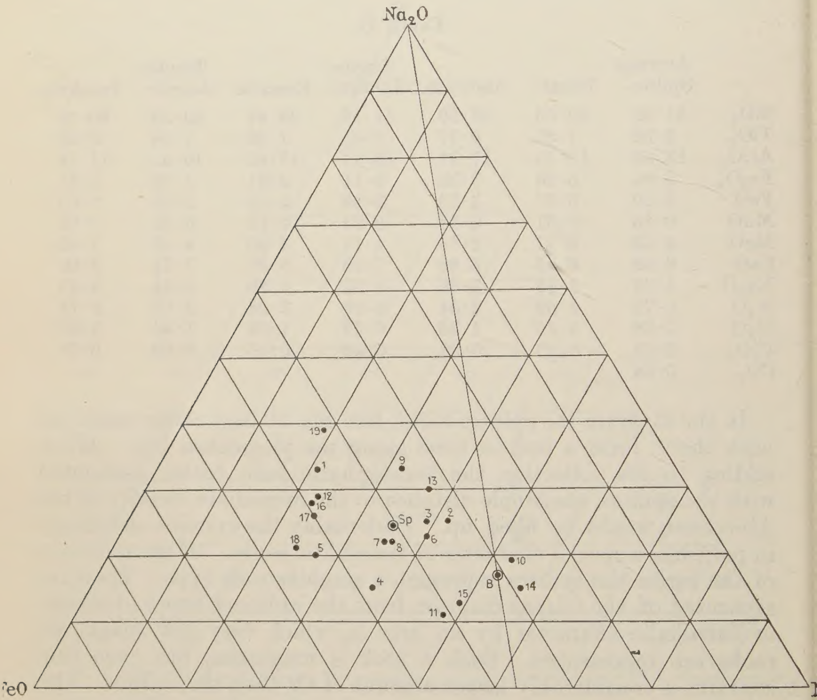

Fig. 2.

the apex at Na_2O represents all points with the same relation of MgO and (Fe, Mn)O as in the basaltic average. The only points falling on the MgO-side of this line are an An-rich variolitic variety of the Australian rocks and one of the Kiruna greenstones, the analysed intrusive rock No. 4 of Table 1. According to Benson, the variolite belongs to a group of intrusive rocks geologically different from the spilites proper, though they are referred to the same period of vulcanity. As mentioned before, the same is the case with the greenstone from Kiruna. The other point of the same intrusive

(No. 15) is situated close to the left of the line. These relations would speak for the assumption that the intrusive rocks analysed should not really be referred to the true spilites. For the rest, all the spilites, as also the diabases associated with them, are essentially richer in FeO. Even when the An-rich members of the spilitic series cannot, on account of their felspar mixtures, be definitely separated from ordinary basalts or diabases, nevertheless the relations as to the FeO-MgO-proportions speak for a difference. The anorthite-rich members of the spilitic series would thus generally be richer in ferrous iron. However, the analytic material on this point is still scarce.

THE COMPOSITION OF THE ORIGINAL FELSPAR OF THE SPILITES.

When discussing the problem of the original felspar of the spilites, the starting point will be the following consideration : In the rocks containing epidote, calcite and chlorite the physical relations at the time of the generation of these compounds were of such a nature that the anorthite was not stable. A certain solubility of some small quantity of An in the albite, possibly 2–5 per cent at most, may be admitted, even under the circumstances mentioned, but if we find in the rocks a plagioclase richer in anorthite, we may conclude that it is a remainder from the original felspar, formed during the consolidation of the magma. In the rocks rich in decomposition products the prevailing felspar is invariably a pure albite, excepting rare instances of more calcic remains. In rocks poorer in decomposition-products the felspar is in many cases pure albite. As the same secondary minerals are present, although in smaller amounts, we may conclude that the pure albite is nevertheless secondary in nature, though the quantity of the anorthite molecules decomposed was smaller. Lastly we find among the spilites rocks which are evidently very little altered, in which the felspar must be admitted to be primary and the dark minerals too are but little or not at all changed. A very instructive instance of spilites of this kind is provided by the Australian rocks described by Benson. In the districts investigated by him we find a continuous series of keratophyric, spilitic, and doleritic lavas (compare the diagram of Fig. 1) the minerals of which answer to true magmatic consolidation products and show few signs of alteration. There is little reason to doubt that the rocks are still composed mainly of the mineral assemblages formed at their consolidation. According to the description the felspar is dominantly albite or albite-oligoclase. The determination indicate a composition of about An_7–An_{15}, though oligoclase and in rarer cases andesine may occur as kernels. In doleritic varieties the composition Ab_{52} An_{48} was recorded. Felspars of similar mixtures are present in the norm of the spilitic rocks of other districts described and may also actually have occurred in the original rocks, though at present the minerals are more or less altered.

When calculating the norm of the Australian rocks, and of spilitic rocks in general, we find that the plagioclase formula, as also the mineral assemblage recorded, do not tally with the actual relations in the rocks or with those which may be supposed to have existed in the unchanged rocks. This is a well-known fact pointed out by earlier authors. A certain proportion of the anorthite molecules must have entered into the pyroxene, thereby contributing to the acidic character of the plagioclase. The phenomenon at the same time implies a contribution of SiO_2 to the dark minerals. This is the reason why olivine or pseudomorphs of it are so seldom reported from the spilites, although the analyses in some cases show a low percentage of SiO_2, and the norm contains a considerable proportion of orthosilicates. This process can be regarded as a sort of resorption, tending to produce metasilicates at the expense of the anorthite molecules. At the same time it accentuates the sodic character of the actual felspar caused by the deficiency in alumina.

The main reason for the opinion that a change of chemical composition has occurred in the spilites seems to be the textures of the rocks, which, according to the authors, imply an earlier crystallization of the felspar than of the pyroxene. Now we need not suppose an acidic felspar in all spilites. Many of the rocks reproduced in the diagram of Fig. 1 may have had or still have an average plagioclase with 20–40 per cent of anorthite. The problem is thus limited to the varieties richer in soda, e.g. to some of the Australian rocks, to the Finnish spilites from Karelia, and to the most Ab-rich Kiruna greenstones. For the last-mentioned rocks the writer himself was earlier inclined to assume an original calcic felspar. This view, however, does not seem to be necessary. For the Karelian rocks a similar assumption of a basic earlier plagioclase is put forward by Eskola. This author bases his opinion on the relations of the binary system albite-clinopyroxene,[1] in which the eutectic point lies close to the albite, or at about 97 per cent albite. The investigation of this system has been made on iron-free material. As to the relations in the system when MgO is replaced by FeO we do not know more than the one fact that the melting temperature for the FeO-rich component will be lowered. In the magmatic rocks this is shown by the order of the layers in the dark minerals, when they are zoned, the FeO-richer mixtures always crystallizing after the MgO-richer ones, even when the difference of the composition is not great. As to the extent of the lowering of the melting point, when the MgO-diopside is replaced by the corresponding FeO-component, we do not know anything definite. Some statements are advanced by Doelter implying a lowering of 150–200 degrees,[2] but even though this figure is uncertain, a lowering of the melting point must occur. Most probably this will alter the position of the eutectic point, displacing it towards the diopside. The same holds good for the system diopside-anorthite as well. As is shown in the foregoing pages, the spilites are FeO-rich rocks. The molecular relation of (Fe, Mn)O to MgO in the analyses of the rocks from Aunus and Kiruna is 66–70 per cent of (Fe, Mn)O to 30–4 per cent of MgO. In the Nundle spilite most rich in normative albite the corresponding figures are 52 per cent (Fe, Mn)O to 48 MgO.

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[1] N. L. Bowen, *Am. J. Sc.*, xl, 1915, p. 163.

[2] C. Doelter, *Handbuch der Mineralchemie*, vol. ii, pt. i, p. 528.

Moreover the spilites are not pure binary mixtures. The felspar at present contains some anorthite and in the altered rocks the original amount may have been still greater. When starting from the two analysed Karelian rocks in which the clinopyroxene remains intact, we obtain in the norm a plagioclase with 14 per cent of anorthite. Some part of the anorthite has in reality entered into the pyroxene. Admitting the clinozoisite of the mode calculated by Eskola to be an alteration-product of former anorthite in the plagioclase in which it is now distributed, we should obtain a felspar containing about 10 per cent anorthite. This we may accept as the approximate primary felspar.

An estimation of the course of crystallization of the separate minerals in a rock on the basis of texture is a somewhat complicated matter. For this question the relations in the Karelian rocks give the best information because of the preservation of the pyroxene and owing to the excellent and explicit description of them. In the uralitized and more altered rocks many of the details of the boundaries of the minerals are obliterated. When discussing the textural relations we must take into consideration the different shapes of the separating crystals and the different velocities of their growth in different directions. When growing more rapidly the plagioclase separates as thin laths or tables, the pyroxene as more isometric grains. Where an edge of a felspar crystal meets a grain of pyroxene during the crystallization the edge of the plagioclase will be enclosed by the pyroxene, although both are growing simultaneously. The result will be that the plagioclase, when it does not become wholly enclosed in the pyroxene, at the end of the crystallization is somewhat thicker in the free part than in the enclosed. And inversely a pyroxene grain, when meeting a felspar table on the flat side, will be partly enclosed by the latter or make some "impression" on it. These are exactly the relations reproduced in the figures from the Aunus rocks (pp. 14 and 20). From structures of this kind it will be difficult to conclude anything as to the mineral that was the first to separate from the magma. On the other hand, it is likely that both the main components, at least to a great extent, separated simultaneously.

In Fig. 3 the two points of the Karelian spilites are plotted in the ternary diopside—plagioclase diagram of Bowen. The points represent the relative amounts of pyroxenes, albite, and anorthite of the norm: quartz, magnetite, ilmenite and apatite—amounting together to 10·5 and 22 per cent—being omitted. Neglecting the possibility of the appearance of olivine, a pyroxene will be the first mineral to separate from a rock magma of the composition of the points. The crystallization has not in reality strictly followed the straight line indicated on the diagram on account of the felspar molecules which have entered into the pyroxene of the rocks. In reality the lines of crystallization should be a little curved towards the Ab-diopside side. As the pyroxenes contain some small amount of alkalies, albite molecules, besides anorthite, must have entered into the crystallizing pyroxene, to a small extent reducing the curve of the arrows, which may have been slight. The eutectic line on the diagram will soon be reached and then followed by the further crystallization. The textural relations of the rocks therefore would be understood on the basis of the MgO-diopside diagram presented. Now the site of the eutectic line is not the one corresponding to a FeO-rich pyroxene. As shown above, the entrance of FeO into the diopside will cause a displacement of the line towards the diopside corner, and to judge from the relations in the binary systems, the displacement will probably be greater on the diopside-anorthite side than on the diopside-albite side. This is indicated by the arrow on the figure. The two points of the rocks will thereby

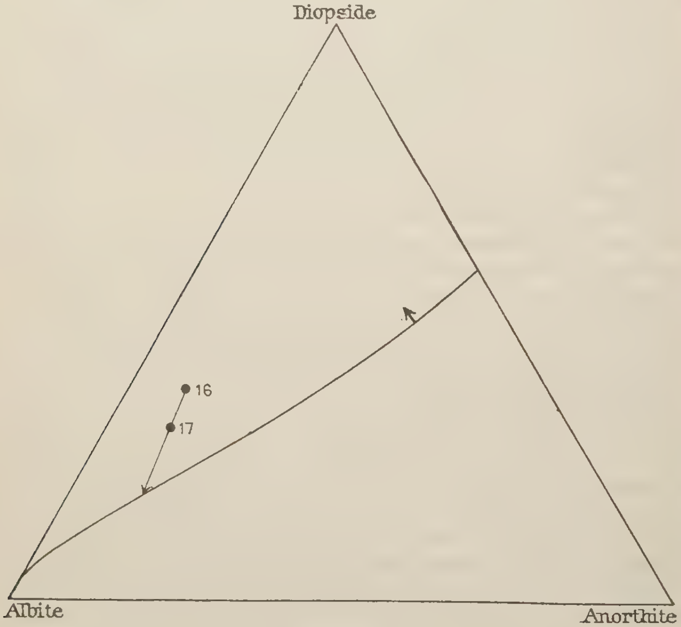

Fig. 3.

be located in the vicinity of the eutectic line, and this will be reached earlier by the crystallization. The amount of pyroxene and felspar separating simultaneously thus becomes in reality greater than shown by the diagram reproduced.

From these relations we may conclude that the assumption of an autopneumatolytic alteration of the felspar is not a necessary consequence of the textural and mineralogical relations found in the rocks. After the crystallization proper, a secondary alteration of the plagioclase has occurred in most of the described rocks of the spilitic group, and the felspar hereby is invariably changed into a nearly pure albite, the amounts of anorthite exceeding 2–5 per cent having been converted to epidote or calcite. There is little ground for the hypothesis of a substantial change of the CaO-Na_2O ratio of the rocks through these mineralogical alterations, otherwise than locally owing to an uneven distribution in the rocks of the alteration products.

ON THE NATURE OF THE MINERAL ALTERATION OF THE SPILITES.

By several authors the highly decomposed stage of many of the spilites described, as also the often richly vesicular structure, are considered to be evidence of a high content of solutions in the magma. Though the hypothesis of an autopneumatolytic change of the CaO–Na_2O ratio of the rocks is not necessary and finds no support in their chemical and petrographical relations, yet it is possible that an alteration of the minerals has occurred in close connection with the consolidation owing to the water and carbon dioxide contained in the magma. This assumption is possibly correct, but as to the time of the mineral alterations we do not know anything with certainty. All that can be said is that a large content of water and carbon dioxide is not necessarily inherent in the spilite magma. This is shown by the Australian rocks and also by the Kiruna greenstones. Even in the most Ab-rich members of the latter, the H_2O-content is not greater than 0·8 and 0·94 per cent, carbon dioxide at the same time being absent or amounting to 1·28 per cent. The alteration of the minerals can also be explained thus: the water of the magma was to a greater or lesser extent retained in the glassy base which can often be traced in the effusive rocks. This water will sooner or later act on the material of the glass and on the separated minerals, producing alteration. This alteration, however, need not necessarily occur in connection with the solidification of the lava.

On the other hand, no relations will be more favourable for secondary alterations than the vesicular consistency of many of the rocks and the occurrence of the same as flows among muddy and shaly strata, which is the case especially with the British spilites. The circulation of water in the porous rock-mass must be greatly favoured by these circumstances.

SUMMARY.

An average analysis is made of an altered intrusive greenstone occurring in the zone of the Kiruna greenstones with the special object of proving whether any local change of chemical composition is occasioned during the alteration processes by the uneven distribution of epidote, as was earlier supposed by the writer. The analysis confirms this, but it also shows that chemical inhomogenities must originally have occurred in the rock-mass. The relations found thus do not indicate great local changes of the chemical composition during the mineral alteration processes still less a change of the bulk composition of the rocks.

A comparison of a number of analyses of spilites and related An-richer rocks affords the following facts: among them there occurs a small group of An-rich members, which are designated here as diabases. Most of the analyses refer to rocks richer in albite, which are here called spilites in the proper sense. In the felspar diagram the projection points of the calculated felspar mixtures of spacing the rocks form a narrow zone close to the plagioclase line extending from 7 per cent An to 58 per cent An. As the dividing point between the diabases and the spilitic members a mixture with about 40 per cent An is accepted. When adding to the diagram the keratophyric rocks associated with the spilites, the whole distance from about 60 per cent of An to the immediate vicinity of the Ab-corner would be filled up.

Between the spilites and other rocks of equal femic composition and of about equal SiO_2 content there exists in the felspar diagram an area in which very few rocks are represented. Petrographically the spilites are thus distinguished as a special rock-type. The boundary towards the ordinary basalts and diabases at the An-rich end of the series on account of the relations of the felspars alone is more dubious, as the individual basalts or diabases may be very poor in potash, but a difference seems to exist here also.

Other chemical qualities characteristic of the spilites are deficiency in alumina and high content of ferrous iron and of TiO_2. The low percentage of Al_2O_3 is the main cause of the soda-rich composition of the felspar, as the CaO-content of the rocks is not low. The An-poor composition of the felspar in the rocks, furthermore, is accentuated by the entrance of An-molecules into the pyroxene during the crystallization of the magma, the generation of olivine being thereby prevented. This mineral, or pseudomorphs of it, is seldom recorded from the spilites. The high content of FeO is distinctive, not only for the spilites proper but also for the diabase members truly belonging to the series.

The importance of the high content of FeO for the course of crystallization in the An-poor members of the spilites is discussed. The consequence is found to be a change of the eutectic ratio of pyroxene and plagioclase contained in the concentration-diagram

of plagioclase and pure MgO-pyroxene. The eutectic line for pyroxene and plagioclase during the crystallization of the magma will thus be reached earlier than shown by the diagram. In this way the textural relations of the rocks are explained without the hypothesis of autometamorphic changes and of an earlier An-rich plagioclase. In the appearance and mineral composition of the rock there is nothing compelling an assumption of this kind, unless the alteration of the minerals to compounds richer in water and carbon dioxide is referred to the period of consolidation. This would imply the fixing in the consolidated rock of these elements, but not a change of the other oxides. As to the time of the generation of the secondary minerals we do not know anything with certainty. The fact that the spilite group includes members which are poor in water and carbon dioxide, or are not decomposed at all, shows that a high content of these compounds is not necessarily inherent in the spilitic magma.

On Rock Glass, and the Solid and Liquid States.

By Leonard Hawkes, D.Sc., F.G.S., Reader in Geology, Bedford College, London University.

THAT the significations commonly applied to the terms " solid " and " liquid " are confusing is illustrated by the indefinite position assigned to the glasses in any classification of the states of matter; for the petrologists, following Tammann, accept the apparent contradiction that glasses are both amorphous solids and super-cooled liquids. Crystals are designated " true solids ", thus implying a stigma to the amorphous solids which appears to be unwarranted. Within the last few years much has been learnt regarding the differences between glasses and liquids and the phenomena attending their interchange of state, and the time is opportune to review the subject and endeavour to attain greater rationality in the use of terms. As at present used the term " solid " has too broad a basis. It is unsatisfactory to consider a number of properties in the definition of a primary state of matter. Terms are then used in different senses by different—and even the same authors; the history of science affords many instances of barren controversy occasioned by this practice.

The main confusion is due to the reference, often in the same sentence, to two radically different conceptions of the differences between solids and liquids; one based upon mechanical properties or behaviour under stress, and the other on the nature of molecular aggregation, the " solid " designation of glass relating to the former, the " liquid " to the latter. The usage must be confined to one of these conceptions, and there is no doubt that the one based on mechanical properties should be adhered to, for not only has this the authority of priority, but the latter differences are fully expressed in the terms " crystalline " and " amorphous ".

We have a fourfold classification of non-gaseous matter based upon the arrangement of the molecules and the mechanical properties of the aggregate. In the crystalline state the atoms are arranged to form the regular repeating pattern of the space lattice: in the amorphous state there is no such arrangement. Leaving for the present the precise definition of " solid " and " liquid " we have the following states :—

Amorphous liquid (liquids).
" Crystalline " liquid (liquid " crystals ").
Crystalline solid (crystals).
Amorphous solid (glasses).

It is doubtful whether any lattice is present in liquid " crystals ", probably there is only a parallel alignment of elongate molecules, in which case these substances are not crystals as here defined. The terms " liquid ", " amorphous ", and " crystalline " may be replaced by " fluid " " isotropic ", and " anisotropic " respectively.

GLASS—A SOLID.

In considering the behaviour of matter under deforming stress two properties must be distinguished, rigidity and strength. Rigidity is shown by a return movement on the release of stress, and strength when a definite stress is required to effect continuous deformation. Some authors define the solid and liquid states on the basis of rigidity, others on the basis of strength, and as rigidity may be present without strength, confusion arises in the designation of some substances. There is, however, agreement that substances lacking both rigidity and strength are liquids, and those possessing both are solids, and it is clear that the magma is liquid, and rock glass at atmospheric temperatures is solid.

The classification of glasses as liquids has been advocated on the ground that " the change in viscosity is a continuous one, and no temperature can be chosen as the freezing point, the point at which the liquid becomes solid ".[1] The difficulty in determining a solidification point would seem to provide no adequate reason for classifying solids as liquids. Some crystalline substances pass so gradually into the amorphous state that their melting points cannot be found, but we do not then deny the fundamental nature of the change and regard these crystals as representing a super-cooled amorphous state. A super-heated liquid is not gaseous, but possesses the properties of a liquid under conditions governing the stability of the gaseous state ; similarly a super-cooled liquid possesses the properties of a liquid under conditions governing the stability of the solid state. We may note further that glasses are not necessarily

[1] G. Tammann, *The States of Aggregation*, 1925, p. 3.

in the super-cooled state. The acid aluminium silicates may exist as glasses at temperatures above their melting points; it is for this reason that it has not been possible to induce albite and orthoclase to crystallize from their pure dry melts.

Some petrologists may seek to justify the view that rock glasses are not true solids on the ground that the glassy state in rocks proves unstable within the range of geological time, and under temperature conditions which are unknown; but it is the glassy, not the solid state, which is unstable. Glasses do not pass into the liquid state under the conditions of their temporary stability; the property of solidity is permanent. It may be noted that rock glasses are remarkably stable under the temperature conditions prevailing in the outer part of the earth's crust. Many examples are known of rocks in which the glassy condition has persisted for millions of years, and some of them still exhibit strain polarization. These glasses commonly contain considerable amounts of water (up to 10 per cent), and there is some evidence that this water inhibits devitrification.[1]

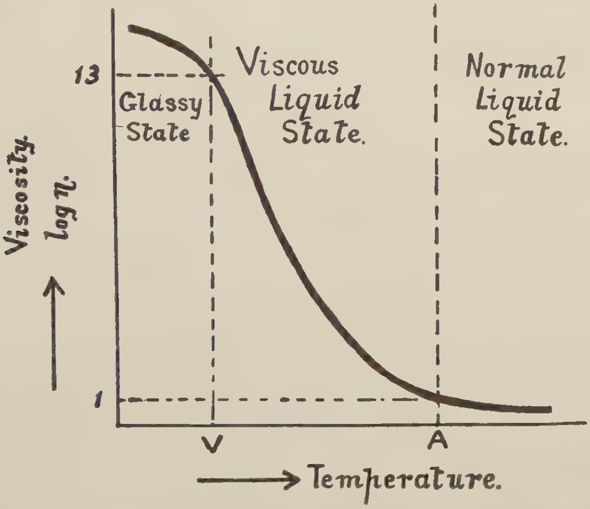

FIG. 1.—Viscosity-temperature relations of the glass-liquid system.

THE VISCOSITY OF THE GLASS-LIQUID SYSTEM.

In petrological works the impression is commonly given that in the formation of glass by the gradual cooling of a liquid the viscosity shows a gradual and uniform increase, but this is not the case. "The viscosity of a liquid increases with increasing undercooling, and in a rather narrow temperature interval it increases very rapidly to values characteristic of solid crystals ",[1] and again :— " the viscosity increases extraordinarily in a certain temperature interval ".[2] The diagram below, taken from Tammann[3] and Berger,[4] gives the viscosity-temperature curve for the glass-liquid system. This curve is found for organic substances as well as for silicates. In the common artificial glasses the temperature of " A " is ca. 1200°, and of " V " ca. 550°.

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[1] E. M. Anderson and E. G. Radley, *Quart. Journ. Geol. Soc.*, lxxi, 1915, p. 210.

In the normal liquid state the viscosity increases slightly with cooling. At the " aggregation temperature " (A),[5] which for single substances commonly coincides approximately with the melting point, the rate of increase augments until the very rapid increase takes place, which is followed by a small and steady rate. The point (V) marks the attainment of the hard and brittle glassy state, and is called the vitrifaction point. The curve demonstrates the existence of three states—normal liquid, viscous liquid, and glassy ; in the viscous liquid region the viscosity increases from 10 to about 10^{13} poises. The temperature " V " varies with the substance, but remarkably enough, in all substances it occurs at a viscosity value of from 10^{13} to 10^{14} poises.[6]

THE SOLID AND LIQUID STATES.

No definition of " solid " and " liquid " can be based on a combination of the properties of rigidity and strength, as rigidity may be present in a substance without strength. Neither will the use of either property separately be satisfactory, for it is impossible in many cases to determine with any precision the temperature at which, on cooling, rigidity or strength is attained.

The clue to a workable definition is given by Jeffreys : " We . . . . recognize the fluid state of a substance by the absence of rigidity, and by the smallness of the viscosity in comparison with that in other states of the same material. Other states characterized by high viscosity, with or without rigidity or strength, will be called solid ".[7] The reference to rigidity may be omitted, and the definition restricted to a basis of contrasted viscosities ; it is only necessary to fix the boundary between the two states, i.e. the solidification or liquefaction point.

A solid has one liquefaction point, but a liquid has two possible solidification points, the vitrifaction and crystallization points.

In the glass-liquid system we adopt the vitrifaction point " V " as a solidification point of the liquid, and the liquefaction point of the glass. It is advisable to restrict the term " melting point " to crystals, the melting point being the temperature at which the crystalline and amorphous states are in equilibrium. The melting point of a substance is commonly a higher temperature than its vitrifaction point, but it may be a lower one, as in the case of albite.

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[1] G. Tammann, loc. cit., p. 3.

[2] G. Tammann, *Journ. Soc. Glass Techn.*, ix, 1925, p. 170.

[3] G. Tammann and W. Hesse, *Zeitschr. f. anorg. Chem.*, clvi, 1926, p. 254.

[4] E. Berger, *Glastechn. Ber.*, v, 1927, p. 395.

[5] G. S. Fulcher, *Journ. Amer. Cer. Soc.*, viii, 1925, p. 339.

[6] M. Michel-Samsoen, *Compt. Rend.*, clxxxii, 1926, p. 517.

[7] H. Jeffreys, *The Earth*, 1929, p. 183.

The viscosity-temperature relation for the crystal-liquid system of a single substance is of the same general character. The change in viscosity occurs abruptly on crystallization, the intermediate viscous-liquid state being absent, and the melting point is the solidification point.

A comprehensive definition may be framed as follows:—"A non-gaseous substance may exist in two states, the solid state with higher viscosities at lower temperatures, and the liquid state with lower viscosities at higher temperatures. The solid state is crystalline or glassy. Excluding the viscosity changes which may accompany the transformation of the crystalline solid into glass, the temperature at which the viscosity of the solid state exhibits a sudden diminution on passing into, or retaining, the amorphous state, is the liquefaction point of the solid and the solidification point of the liquid."

The definition excludes viscosity changes due to crystalline polymorphic transformations. The vitrifaction point is governed by pressure.[1]

In the case of liquid solutions not of eutectic composition, there is a temperature range of crystallization, which in magmas may cover hundreds of degrees; thus these magmas solidify more rapidly by vitrifaction than by crystallization.

THE CHANGE IN THE STATE OF MOLECULAR AGGREGATION ON THE VITRIFACTION OF LIQUIDS.

The view that, in respect to the nature of molecular aggregation, glasses may be considered to be super-cooled liquids, has been based upon the supposed continuity of change of physical properties with temperature changes in the glass-liquid system, and the absence of any heat effect within the temperature range of softening. It was thought that "only the viscosity varies in an unique manner",[2] but recent work, especially that of American investigators, calls for revision of this view.

(*a*) *The Heat Effect on Vitrifaction.*

The melting point of a crystalline substance can usually be identified on the heating curve by an absorption of heat on liquefaction. It has been shown that a similar effect accompanies the liquefaction of glass; there is an exothermic effect on vitrifaction, and an endothermic effect on liquefaction. On heating, the relative cooling at one point "proceeds with such rapidity that this effect takes on a character very similar to the endothermic effect observed in crystalline media when some transformation takes place which involves a change of state or crystal form ".[1] The temperature at which the heat effects are noted depends upon the rates of heating and cooling ; the exothermic effect is shifted towards the lower temperatures, and the endothermic effect towards the higher temperatures, by an increased rate of temperature change. There is little doubt that the heat effect is due to the same change in constitution which produces the viscosity change,[2] the dependence of the location of the effect upon the rate of temperature change is explained by the slowness of the molecular changes under the conditions of high viscosity.

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[1] G. Tammann and W. Jellinghaus, *Ann. d. Phys.*, ii, 1929, p. 264.

[2] G. Tammann, *Journ. Soc. Glass Techn.*, ix, 1925, p. 171.

That the heat effect has often escaped notice is not surprising when we consider that the more considerable effects accompanying the melting of crystals may be incapable of detection when the melt is highly viscous. Day and Allen found that the plagioclase felspars melt over a considerable range of temperature, and that in plagioclases of greater acidity than $Ab_4\ An_1$ " all trace of the heat of fusion was lost ". " A substance of this kind (albite) . . . passes gradually from crystalline to amorphous at temperatures which can be considerably varied by merely changing the rate of heating ".[3]

(*b*) *Changes in Other Properties accompanying the Viscosity Increase on Vitrifaction.*

The following properties show an abrupt change in the neighbourhood of the vitrifaction point [4] :—

(1) Specific heat.[5]
(2) Thermal expansion.[6]
(3) Index of refraction.[7]
(4) Electrical conductivity.[8]
(5) Density.[9]

An abrupt change in the size of the X-ray diffraction halo is observed at the temperature at which the other properties show a discontinuity.[10]

Thus there are many indications that a fundamental change in the state of molecular aggregation takes place on the vitrifaction of liquids, i.e. that glasses are not liquids at low temperatures.

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[1] A. Q. Tool and C. G. Eichlin, *Journ. Opt. Soc. Amer.*, iv, 1920, p. 355.

[2] V. H. Stott, *Journ. Soc. Glass Techn.*, ix, 1925, p. 207.

[3] A. L. Day and E. T. Allen, *The Isomorphism and Thermal Properties of the Felspars*, Carneg. Inst., Washington, 1905, pp. 44 and 74, and fig. 9, p. 42.

[4] For a bibliography, see E. Berger, loc. cit.

[5] G. S. Parks and H. M. Huffman, *Journ. Phys. Chem.*, xxxii, 1928, p. 1366, and xxxi, 1927, p. 1842.

[6] M. Michel-Samsoen, loc. cit.

[7] A. Q. Tool, Tilton, and Hill, *Journ. Opt. Soc. Amer.*, xii, 1926, p. 490.

[8] H. Schönborn, *Ker. Rund.*, xxxiii, 1925, p. 397.

[9] A. Q. Tool and E. E. Hill, *Journ. Soc. Glass Techn.*, ix, 1925, p. 185.

[10] P. Krishnamurti, *Ind. Journ. Phys.*, iv, 1929, p. 99.

The nature of the change is not here discussed, the question has hardly passed beyond the speculative stage.[1]

When the same mixture is cooled at different rates, glasses are obtained which differ in properties, and some authors consider that these differences are of a fundamental constitutional nature and are not due to internal stresses. If this is the case, quickly chilled glasses may be, in part, undercooled " with respect to the completion of many processes normal to the vitreous condition ".[2]

Professor W. E. S. Turner informs me that changes are found in the properties of glass on cooling below the vitrifaction point, corresponding to alterations of 8 or more per cent in the value of the property at each inflexion, which he suggests may be compared with the transition points noted in crystals.[3]

The " glass " of the petrologist is a solid which appears wholly amorphous under analysis by light rays, but X-ray examination may reveal the presence of crystals too small to be detected by the former method.[4] There can be no doubt that the true glassy substance is non-crystalline, but in practice we may continue to class as glasses those solids " which contain so few molecules in the crystalline state that they may be spoken of as amorphous ".[5]

A NOTE ON PORPHYRITIC TEXTURE.

It is recognized that some cases of porphyritic texture are not due to an uneven rate of cooling, nor to the presence of any constituent in excess of the others, and that all crystals, porphyritic and groundmass, have grown after magmatic emplacement, with uniform cooling.[6] The sudden increase in viscosity near the vitrifaction point serves to account for these cases. Tammann shows that, with undercooling, the number of centres of spontaneous crystallization increases greatly, and attains a maximum, in the region of abnormal viscosity increase, whereas the rate of crystal growth reaches a maximum before this increase occurs.[7] It is thus clear that with an even cooling rate, and one sufficiently rapid to take the crystallizing magma into the region of the vitrifaction point before the completion of crystallization, the first formed crystals will be larger than the later ones.

On this view porphyritic texture may be due to the arrival of the partially crystallized magma in the neighbourhood of the vitrifaction point. As basic magmas reach this point more rarely than acidic ones, we may expect porphyritic texture to be rarer in the basic than in the acidic rocks. This is known to be the case.

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[1] See E. Berger, loc. cit., W. Rosenhain, *Journ. Soc. Glass Techn.*, xi, 1927, p. 77, and the papers in the " Symposium on Glass," ibid., ix, 1925.

[2] A. Q. Tool and E. E. Hill, loc. cit., p. 206.

[3] See *Journ. Soc. Glass Techn.*, xii, 1928, pp. 31, 52, 169, 287.

[4] R. W. G. Wyckoff and G. W. Morey, ibid., ix, 1925, p. 266.

[5] F. Eckert, ibid., ix, 1925, p. 269.

[6] L. V. Pirsson, *Amer. Journ. Sci.*, vii, 1899, p. 271.

[7] G. Tamman, *Journ. Soc. Glass Techn.*, ix, 1925, p. 173.

I am indebted to Professor W. E. S. Turner for helpful criticism during the preparation of this paper.

SUMMARY.

The solid and liquid states are defined on the basis of the viscosity-temperature curve.

Glasses are amorphous solids. Their state of molecular aggregation is fundamentally different from that of liquids: they are not super-cooled liquids.

It is suggested that porphyritic texture may result from an even rate of magmatic cooling on account of the abnormal increase in viscosity which occurs before vitrifaction.

Laterite.

By J. B. SCRIVENOR, M.A., F.G.S.

IN the first place let us deal with the origin of the word. It was first used in 1807 by F. Buchanan in *A Journey from Madras through Mysore, Canara, and Malabar.* In dealing with the iron-ore seen during his journey he wrote:—" In all the hills of the country the ore is found forming beds, veins, or detached masses in the stratum of indurated clay, that is to be afterwards described, and of which the greater part of the hills of Malabar consists. . . . What I have called indurated clay . . . is one of the most valuable materials for building. It is diffused in immense masses, without any appearance of stratification, and is placed over the granite which forms the basis of Malayala. It is full of cavities and pores, and contains a very large quantity of iron in the form of red and yellow ochres. In the mass, while excluded from the air, it is so soft, that any iron instrument readily cuts it, and is dug up in square masses with a pickaxe, and immediately cut into the shape wanted with a trowel, or large knife. It very soon after becomes as hard as a brick, and resists the air and water much better than any bricks I have seen in India. . . . As it is usually cut into the form of bricks for building, in several of the native dialects it is called the brick stone. . . . The most proper English name would be Laterite, from Lateritis, the appellation that may be given to it in science."

The Latin root from which the word is derived is *later*, a brick or tile. Note that in the passage above it is clear that Buchanan meant the term to be applied to the " indurated clay " and not to the iron-ore. He says it contains a very large quantity of iron in the form of red and yellow ochres and describes how it hardens on exposure and is used for building in the form of bricks.

What Buchanan was describing is a common weathering product of rocks, found in most tropical countries. People who had seen the red and yellow indurated clay in India carried the word to other countries and applied it to red and yellow weathering products they saw there. Thus any red soil or soil mottled red and yellow came to be called laterite, although it might not be possible to cut it into bricks, which was the real test of similarity to Buchanan's laterite, and, worse still, the name came to be applied to hard masses of iron-ore in red or mottled soils, especially by engineers, who in Malaya used to call them, and possibly still call them, "No. 1 laterite," because they form the best laterite road-metal. So here were two deviations already from Buchanan's original intention regarding the use of the word.

In India the use of the word spread, but it was not until 1903 that general interest in the chemical composition of laterite was aroused. In the GEOLOGICAL MAGAZINE for that year Sir Thomas Holland had a paper on the "Constitution, Origin, and Dehydration of Laterite" in which he said that if the term "clay" is restricted to substances having a basis of hydrous silicate of alumina, it is wrong to call laterite "ferruginous clay" because in laterite the alumina exists, as in bauxite, in the form of hydrous oxides (op. cit., pp. 68–9). He also said (p. 61) "Professor Bauer has now shown that laterite reproduces 'the essential characters of bauxite'".

In the same volume of the GEOLOGICAL MAGAZINE H. and F. J. Warth published analyses of Indian laterites (pp. 154–9). On p. 159 they wrote :—"Laterite is bauxite in various degrees of purity, from the richest wocheinite down to such specimens in which the free alumina has entirely disappeared." It will make this paper easier to follow if I add that bauxite is an amorphous hydrate (hydrous oxide) of aluminium generally having the composition $Al_2O_3.2H_2O$, while there are two other crystalline hydrates of aluminium, diaspore ($Al_2O_3.H_2O$), and gibbsite ($Al_2O_3.3H_2O$). Wocheinite is a very pure bauxite, gray, with very little iron oxide. "Free alumina" here means Al_2O_3 not combined with silicic acid or any other acid radicle, but it may be combined with water.

The great majority of people who had come to use the term "laterite" as a common word, engineers, agriculturists and others probably never heard of these analyses at all ; but among geologists, they, and other analyses, gave rise to an unfortunate idea that all laterite contained a high percentage of aluminium hydrate, and that if a decomposition product did not contain a high percentage of aluminium hydrate it should not be called laterite. This latter dictum was queried and a controversy on the subject arose, which lasted for at least two years and was summarized by Dr. L. L. Fermor in 1911 (GEOLOGICAL MAGAZINE, pp. 454, 507, and 559), but, unfortunately, this author, in an endeavour to clarify the position, suggested the use of two new terms, "lateritoid" and "lateritite" which, if adopted, would have made matters worse than ever.

In spite of efforts to prevent it the idea spread among geologists that laterite was essentially a weathering product containing a high percentage of aluminium hydrate ; but in 1923, Dr. C. S. Fox published a memoir on "The Bauxite and Aluminous Laterite

Occurrences of India" (*Memoirs of the Geological Survey of India*, vol. xlix, part 1). In this work Dr. Fox illuminates the position regarding Indian laterite. If it contains enough aluminium hydrate to be used as aluminium-ore it should, he says, be called bauxite (this had been previously suggested by Dr. Fermor), and his use of the term "aluminous laterite" shows that he regards that as a special kind of laterite, not typical laterite. On p. 5 he writes:—"Practically all the bauxites or aluminous laterites occur associated with primary laterite—those which have been formed from various types of rock *in situ*. These bauxite segregations constitute an exceedingly small proportion of the primary laterite of the country. A very small percentage of the secondary laterites have enrichments of aluminous laterite suitable for use as bauxite." So the laterite rich in aluminium hydrate which caused so much interest in 1903 is described in 1923 as "an exceedingly small proportion" of primary laterite and "a very small percentage" of secondary (detrital) laterite. If that is so, and I have no reason to suppose that Dr. Fox is wrong, it is impossible to take richness in aluminium hydrate as the leading characteristic of laterite and it appears to me that popularization on the one hand and enthusiasm over a few analyses on the other have destroyed the value of laterite as a scientific term; while those geologists who insisted on a high percentage of aluminium hydrate as the test of "laterite", are as far from Buchanan's intention as to the use of the word which he originated, as are engineers who call masses of iron oxide in the soil "No. 1 laterite".

In Malaya we have some laterite that fits Buchanan's definition exactly, in Malacca Territory, where schists and granitic rocks weather to a red and yellow mottled mass which, in the case of the schists and perhaps to a small extent of the granite, can be quarried and used as Buchanan describes. But it is certain that the bulk of the alumina is combined with silica, and is not present as free aluminium hydrate. Superficially, it closely resembles specimens I have seen of Indian laterite. An analysis by Mr. J. C. Shenton of this Malacca laterite, over schists, is as follows:—

	Per cent.
Silica	23·60
Titanium dioxide . . .	·86
Ferric oxide	37·94
Alumina	21·60
Manganese	trace.
Zirconia	trace.
Lime	1·20
Magnesia	·45
Sulphuric anhydride . .	3·36
Potash	·34
Soda	·37
Water and loss on ignition .	11·20
	100·92

Among geologists I think it is generally assumed now that if laterite is mentioned, something containing aluminium hydrate is referred to—quite wrongly—but others may refer to a red or yellow soil or to an iron-oxide, and I think that for scientific work the term would be much better dropped.

But from under all this confusion there is one definite piece of information that has emerged, and that is that under certain conditions silicate-rocks produce aluminium hydrate as a final weathering product instead of hydrous aluminium silicates. What those conditions are is not yet certain. Some say tropical conditions are necessary, but that is not proved; or that alternation of wet and dry seasons is required, but that is not proved either. The formation of aluminium hydrate, however, is more marked in rocks with a low, than with a high silica percentage. The change that takes place is a step beyond the formation of the hydrous silicate, which is broken down, silica being carried off in solution, and hydrate remaining.

In Malaya, in Indo-China, and in the Netherlands Indies the change in " acid " granitic rocks, which have a high percentage of silica, does not go beyond the formation of hydrous silicate of alumina, except perhaps for a small proportion hard to prove and, therefore, the soil is clayey owing to the presence of kaolinite and perhaps halloysite. In less acid or " basic " rocks on the other hand, when weathered, there is an appreciable amount of aluminium hydrate; but it is curious that the only occurrence of hydrate in large percentage in Malaya is as nodules of a white or creamy colour above schists, e.g. at Redhills, Kinta; Rawang; and in Malacca—which are of no economic importance. In Kuantan is situated the only large area where basic rocks form the soil. This is about 30 square miles of soil derived from dolerite, north and north-west of the township of Kuantan. The soil resembles the volcanic soils of Java, being derived from a similar rock.

But what particularly concerns us here is whether laterite, in any sense of the word, is of importance in agriculture and forestry. Rocks supply three important plant-foods, calcium carbonate ($CaCO_3$), potash (K_2O), and phosphorus pentoxide (P_2O_5). Iron and magnesia are of minor importance, and as far as I am aware, alumina is of no importance as a plant-food.

First consider the red, yellow, and mottled soils formed over " acid rocks ". Here we are dealing really with ordinary soils and we expect to get a little $CaCO_3$, only a little P_2O_5, but more K_2O. The hydrous silicate of alumina derived from felspar makes the soils rather clayey unless grains of quartz are abundant. The same is true for the laterite in Malacca and generally for soils over schists, as for soils over acid rocks.

The masses of iron-ore referred to as " laterite " by engineers we need not consider.

Is bauxite, or an aluminous laterite, a good soil? Bauxite is essentially $Al_2O_3.2H_2O$ with Fe_2O_3, SiO_2, P_2O_5, CaO, and MgO as common impurities (Dana, *System of Mineralogy*, p. 251). The analyses of H. and F. J. Warth of certain Indian laterites, which can be described as bauxites and aluminous laterites, show as the main constituents Al_2O_3, Fe_2O_3, H_2O, SiO_2, and TiO_2. CaO and MgO are unimportant; P_2O_5 and K_2O are not mentioned. If the volcanic soils of Java and Kuantan are considered to be laterite on the ground that they contain much aluminium hydrate, then is their richness as soils due to that hydrate? Chemically it is not; the rocks from which the soils are derived yield more $CaCO_3$ and P_2O_5 than acid rocks, and are therefore richer. As a source of plant-foods, therefore, laterite is not of special importance: but mechanically it may be of considerable importance in soils. It may be beneficial or the reverse.

In the case of a weathering product rich in aluminium hydrate the proportion of "clay" is small, or it may be absent altogether. The result is that such soils are earthy, open, and porous. In the case of the Kuantan dolerite soil this may be of importance in allowing the free circulation of plant-foods and perhaps in aeration and growth of roots, but in Java and Malaya such soils are generally stiff, though distinctly friable.

On the other hand soils are frequently so impregnated with iron-oxide that their porosity is reduced or destroyed altogether, which must have a bad effect on vegetation. In the latter case the so-called "laterite" is nothing more than the "iron-pans" of Europe, which are often a source of trouble to agriculturists.

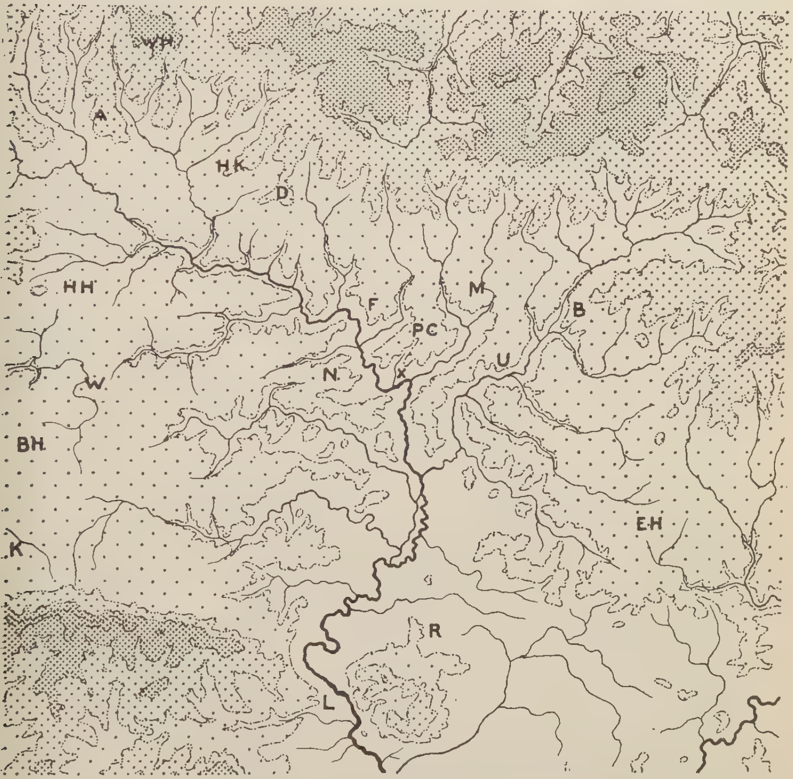
In conclusion I would suggest that the word laterite be used as little as possible. In Malaya we have typical laterite as defined by Buchanan, but it is only weathered rock impregnated with iron-oxide, and contains a large amount of hydrous silicate of aluminium or "clay". On the other hand the word is applied popularly to masses of iron-oxide and red decomposition products which are simply ordinary soils coloured by Fe_2O_3. The formation of large quantities of aluminium hydrate may be of importance mechanically in a soil, but it is unnecessary, and incorrect, to associate that with Buchanan's word "laterite".

Pebbles of Quartzite near Piltdown, Sussex.

By Herbert L. Hawkins, D.Sc., F.G.S., University of Reading.

In July of 1929 I visited the classic locality of Piltdown under the guidance of Sir A. Smith Woodward. After paying homage at the tomb of *Eoanthropus* we descended from the plateau to the low-level gravel terrace that flanks the flood-plain of the River Ouse. At a place known locally as Sharp's Bridge (marked on the accompanying map by a cross) there is a new but already extensive gravel pit. A spot-level on the map near the pit gives the approximate level of the top of the gravel terrace as 38 O.D.; the face of the pit is dug to a depth of from 8 to 10 feet below this level, and seems to reach down to about the level of saturation determined by the water of the river.

The gravel is very well stratified, and the ingredients are roughly sorted in accordance with their size. In our casual inspection of the section we noticed only the features of the larger materials. The great bulk of the pebbles consists of more or less worn fragments of ironstone and ferruginous sandstone clearly derived from the Wealden deposits through which all of the upper reaches of the



Map of part of the basin of the Sussex Ouse, to show position of quartzite-bearing gravel. Scale: ¼ in. to a mile. *A*, Ardingly; *B*, Buxted; *BH*, Burgess Hill; *C*, Crowborough; *D*, Danehill; *EH*, East Hoathly; *F*, Fletching; *HH*, Haywards Heath; *HK*, Horsted Keynes; *K*, Keymer; *L*, Lewes; *M*, Maresfield; *N*, Newick; *PC*, Piltdown Common; *R*, Ringmer; *U*, Uckfield; *W*, Wivelsfield; *WH*, West Hoathly; *X*, Sharp's Bridge Gravel Pit.

valley are cut. In addition to these, there occur occasionally brown-coated subangular flints, which agree so closely with those found in the *Eoanthropus* plateau (about 100 feet above) that it seems safe to assume their derivation from that source.

To our great surprise we found associated with these expected constituents a not inconsiderable number of pebbles of quartzite and vein-quartz. These pebbles are, on the average, larger than any of the other kinds present—the largest that I carried away is 12 cm. across, but there were many of considerably larger size. Most of these pebbles are perfectly rounded—those that are at all subangular have forms strongly suggestive of battered dreikanter. In all superficial attributes these pebbles agree with those so prevalent on the Chilterns in the high-level drifts, and ascribed to the "Northern Drift".

There seems every reason to believe that these pebbles may have been derived from some Triassic pebble-beds (their degree of rounding shows that they were pebbles before their incorporation into the gravel, and no conglomerates of so extreme a degree of coarseness are known from any local "solid" rocks), and the temptation is great to claim for them the same Midland origin which is attributed to similar pebbles in the Thames valley drifts. But it seems more probable, on general grounds, that their source may have been either to the south-west or to the south. There are almost insuperable difficulties on any other hypothesis of their origin.

It was at first thought that these quartzites might represent relics of some Tertiary beach; but they have not been found in the gravel of the *Eoanthropus* plateau (and in view of the intensive study applied to that horizon they may be assumed to be definitely absent from it); so that their introduction into the area would seem to be dated as occurring in Pleistocene times.

Situated in a fairly deep and narrow valley far inland behind the escarpment of the South Downs, these deposits could scarcely be regarded as any sort of "raised beach" (although similar pebbles occur in many so-called raised beaches on the seaward side of the Downs); and indeed the gravel is a perfectly typical river-gravel. Although I have no explanation to offer for this strange occurrence, I have thought it well to publish this note in the hope that others may succeed in tracing the pebbles to their source and so solving the mystery.

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" Red Beds " and Associated Formations in New Mexico. By N. H. Darton. Bull. 794, 1928.

REVIEWS.

Summary of Progress of the Geological Survey of Great Britain, 1928. Part 1, pp. 1–99, price 2*s.*; Part 2, pp. 1–128, 2 plates and numerous text-figures, price 3*s.*

THE Director of the Geological Survey is much to be congratulated on the *Summary of Progress* in its new form in two distinct parts. Rumours are afloat anent a possible Part 3; if it is to resemble Part 2 we sincerely hope it will materialize.

The new arrangement is admirable. Part 1 is mainly devoted to what may be termed the Report on general routine work; and in it is to be found a most interesting account of the work of the " New Arm ", the Gravitational Survey by the Torsion Balance, and the nature of the problems that may be investigated by this means. A course of Magnetic Surveys is contemplated by means of which the results of the Gravitational Surveys may be confirmed and extended. Other features of interest are to be found in the Reports from the different District Geologists; for example, in the Midland District, which includes the classic Shropshire area, a *provisional* classification is suggested for the rocks of the Western Longmyndian; it is perhaps as well to emphasize that it is *provisional*, as things in Shropshire are not always what they seem. From Yorkshire comes the suggestion of the advisability of extending the Lower Coal Measures in a downward direction owing to the relation of the beds belonging to the *Cancellatum* and *Cumbriense* horizons to the occurrence of beds with *Carbonicola*. The Cumbrian division report interesting facts relative to the Borrowdale-Skiddaw Slate-Carrock Fell sequence, and in Northumberland and Durham the southward increase in the number of marine bands in the Scremerston Coal Group is worth attention.

In Scotland the Survey of the Orkneys is disclosing many new and interesting facts relating to the stratigraphy and fauna of the Old Red Sandstone as compared with the Mainland.

In the Palaeontological Section an especially interesting record is that of the occurrence of an Olenellid from South Wales.

Part 2 is devoted to the publication of eight little memoirs of the type that have hitherto been found as appendices. Attention has many times in the past been directed to the interest and importance of these, and it is undoubtedly a great advantage to have them in their present form. All deal with subjects of considerable interest, especially the first four. Nos. 1 and 2 give details of the Gravitational Survey over the buried channel of the Kelvin at Drumry, and over the Pentland Fault at Portobello, and in them the nature of the work and the importance of the results achieved are clearly brought out; No. 3 deals with the Inverbeg lamprophyre on the west of Loch Lomond; the special interest of this dyke lies in the character of its inclusions, particularly those of enallogenetic type. The occurrence amongst these of schists containing staurolite and garnet is, as noticed, strongly suggestive of depth metamorphism; it may perhaps be noted in this connection that staurolite has been found by the reviewer in the Ben Lui Schists of Glen Lyon far west of the Garry, and quite unconnected with any occurrence of the Older Igneous Rocks. We also confess frankly to a delight that this dyke possibly affords some confirmation of the view that the succession from the Highland Border inwards is a descending one.

No. 4 of the little memoirs is palaeontological, dealing with the Zonal Succession in the Coal Measures round Manchester, and is based upon the occurrence of the fresh-water lamellibranchs. The stimulus given to the study of these organisms as a result of the work of Davies and Trueman in South Wales is clearly bearing good fruit, for though the faunas in Lancashire appear to differ somewhat from those in South Wales, most of the Zones (with the exception of the *Similis* Zone) have been recognized, whilst several new species are described and figured in plates which apparently reproduce original drawings by an inexpensive process and show very clearly the features necessary for identification and discrimination.

The whole is so well got up with such clearly printed maps, sections and text-figures generally that we wish this admirable lead might be followed in other quarters.

G. L. E.

VORKOMMEN UND GEOCHEMIE DER MINERALISCHEN ROHSTOFFE.

By G. BERG. pp. x + 414, with 67 figures. Leipzig: Akademische Verlagsgesellschaft, 1929.

IT is a difficult matter to review this book with a balanced mind, because it varies so enormously in value in different parts. When the author is dealing with matters of pure science, it calls forth nothing but admiration, but in his treatment of economic subjects it is obvious that he is completely out of his depth. The first two chapters contain a lucid account of modern views as to the constitution of the different layers that compose the earth, following especially the ideas of V. M. Goldschmidt, with perhaps an unnecessary insistence on the fine structure of atoms and crystals. Then follows an excellent discussion of the concentration of the scarcer elements by magmatic differentiation and its attendant hydrothermal phases, by weathering and by sedimentation. These sections together occupy about 100 pages. It is in the second or systematic part of the book that the inequality of treatment makes itself so conspicuously manifest. Sometimes the author is thoroughly up-to-date, sometimes hopelessly behind the times. For example, the description of the iron ore deposits of England is simply ludicrous: the only types mentioned are Cumberland, the Forest of Dean, and the Blackband ironstones of the Coal-measures. With regard to the Lake Superior region, it is stated that the annual output is 300 million tons. The *Statistical Summary* of the Imperial Institute for 1925–7, the latest available to the reviewer, gives the production for the whole of the United States for 1927 as 63 million tons. In the discussion of oolitic iron ores there is no mention of the work of Cayeux on Lorraine, of Hallimond on British ores, or of Hayes on Wabana. The only reference given for the Sudbury nickel ores is dated 1913, although the output of literature since then has been very great, and the figure of the Broken Hill (N.S.W.) ore-body is entirely out of date. The splendid monograph by Andrews on the last-named is not mentioned.

From these and numerous other instances it can only be concluded that the author has not had access to the non-German post-war literature and, therefore, except perhaps as to German occurrences, he cannot be regarded as a safe guide. If he had read the American and English text-books cited by him on p. 175 he would have been saved from some of his worst blunders.

THE EARTH: ITS ORIGIN, HISTORY AND PHYSICAL CONSTITUTION. By H. JEFFREYS. 2nd edition. pp. ix + 346. Cambridge University Press, 1929. Price 20*s*.

THE UNIVERSE AROUND US. By SIR JAMES JEANS. pp. x + 352, with 24 plates and 24 text-figures. Cambridge University Press, 1929. Price 12*s*. 6*d*.

IT is not proposed here to review these books in the ordinary way, since both of them, and especially the second, deal for the most part with problems outside the scope of geology. The first edition of Dr. Jeffreys' work was dealt with at some length on its appearance: it has now been considerably enlarged and amplified in many ways, with due regard to criticism from various quarters. The other book is mainly astronomical, embodying the latest ideas in this most progressive and astounding of all sciences. The modern applications of atomic physics to the stars veritably make the mind reel.

Both works, however, inevitably deal with one subject of intense interest to all geologists, namely, the age and origin of the earth. Sir James Jeans makes it clear that a solar system must be a rare phenomenon in the universe, since on the theory of tidal disruption planets can only be born if two stars wandering through space happen to approach one another within a distance of some three diameters: the odds against such an approach are enormous. If such did occur and the earth is in reality merely a fragment thus torn off from the sun and subsequently moulded to its present form, is it not permissible, so far as the earth is concerned, to regard this event as the beginning and to ignore whatever may have gone before as irrelevant? For this beginning we may now with some confidence accept a date of from 1,500 to 2,000 million years ago, which gives plenty of time for geological history.

The books differ fundamentally in treatment. Dr. Jeffreys is for the most part abstrusely mathematical, except when he is discussing geological subjects, and sometimes even then, whereas Sir James Jeans clothes his ideas avowedly in simple language, with the intention of making the book intelligible to readers with no special scientific knowledge. Hence there can, of course, be no attempt to compare them even when treating of the same subject. Nevertheless even the most severely mathematical reader cannot fail to enjoy the lucid popular treatment of Sir James Jeans, while it is to be feared that much of the argument of Dr. Jeffreys will remain a sealed book to many geologists, although it should be said that his final conclusions are stated in a form sufficiently clear to be grasped by the non-mathematical mind.

STRUCTURE AND SURFACE. A book of Field Geology. By C. BARRINGTON BROWN and F. DEBENHAM. pp. 1–165, with 104 text-figures and a folding map. Arnold and Co. Price 10*s.* 6*d.*

THIS book is in effect an introduction to the study of land forms in the field, assisted by the use of block diagrams; as such it should certainly make an appeal primarily to students of geography who find the study of the surface of the earth somewhat inexplicable without some knowledge of the underground geology; it will also be useful to the beginner in geology if it serves to make him realize that the fundamental principles of his science may be seen and studied in the country all round him. In this connection chapters viii, ix, and x are admirably clear in illustration and lucid in exposition, but in the earlier chapters the material is not so well arranged, there is some confusion between elementary and advanced knowledge; we should have liked to see all the good advice concerning the construction of geological maps relegated to a later place, for the student of geology and geomorphology has much to learn before he is competent to make such maps: he should certainly have at his fingers ends all the principles put forward in this book, and should be able to "see solid" without the aid of a block diagram. Granted that the block diagram is the easiest way of teaching the student to visualize the actual state of things, it seems open to question whether the reproduction of actual areas on small block diagrams really achieves the aim of the authors. The generalization and simplification necessitated by the reduction may give an entirely erroneous idea of the true state of things. This is unfortunately exemplified only too well in fig. 105, the dissected block diagram of England and Wales. Here the structure of the South Wales coal field as shown gives no idea that it is full of features of absorbing structural and geomorphological interest and the structure of the

Snowdon district appears to be on a par with that of the Pennine Chain!

The *idea* is excellent, but production in book form limits it too severely.

The least successful chapter in the book is that dealing with faults. In the case of *dip* faults there is always an apparent lateral shift of the beds on one side of the fault plane, the amount of shift being dependent upon the dip of the beds, and this effect must be discernible in any *oblique* fault in which there is an appreciable component of dip. In the case of *strike* faulting, on the other hand, the question of the repetition or concealment of beds at the surface is not merely a question of whether the downthrow is *with* or *against* the dip, but in the case of downthrow *with* the dip, the angle of its hade relatively to the dip of the beds. In the case of tensional strike faults there will be repetition of beds at the surface unless the hade of the fault is in the same direction as the dip and at a higher angle, when concealment will occur. With compressional faults concealment will take place unless the fault plane hades in the same direction as the dip and at a higher angle, when repetition will be found at the surface of the ground.

Slides as usual are misrepresented; the essential thing about a slide is that it is a movement that takes place under a heavy load at considerable depths, and it therefore lacks all the accompaniments of relatively superficial overthrusting such as brecciation and mylonitization.

The block diagrams throughout the book are clear and well chosen, though instead of fig. 70 we should have liked to have had one to show how one and the same sill by changing its horizon may appear at several different levels.

G. L. E.

THE MOTHER LODE SYSTEM OF CALIFORNIA. By ADOLPH KNOPF. Professional Paper 157, United States Geological Survey. pp. v + 88, with 12 plates, 26 text-figures and a coloured map. Government Printing Office, Washington, 1929.

THERE has long been a glamour over the early history of gold mining in California, due to stories of the "Forty-niners" and the literary genius of Bret Harte and Mark Twain: consequently some people may be apt to regard the whole thing as an episode of the past. Nevertheless lode-mining is active in the very heart of the old classic localities, in Calaveras, Tuolumne and Mariposa counties, and Angels Camp still exists near the Stanislaus River, as a flourishing town mainly devoted to gardening. Many of the mines have now reached great depths, as much as 4,500 feet, and the ore shoots still persist or even increase in value.

The author of this memoir points out that there is no such thing as a continuous lode, the Mother Lode (Veta Madre) as once supposed: it is more correctly described as a lode-system, consisting of numerous veins and ore-bodies concentrated in a narrow zone, one mile wide and 120 miles long. It is essentially a line of faulting, a shatter-belt, highly mineralized by hydrothermal solutions derived from igneous intrusions. The oldest rocks present are the Calaveras formation, sediments and green schists of Carboniferous age, the latter of igneous origin: all these were metamorphosed and invaded by diorite, granite and other intrusions at the end of the Palaeozoic. The Mariposa formation consists of slates with graywacke, tillites (?) and conglomerates. In late Jurassic or early Cretaceous times the region felt the onset of the Cordilleran revolution; the rocks were isoclinally folded and faulted, reversed faults predominating, and invaded by a plutonic series ranging from serpentine to granodiorite. It was at the end of this phase that the gold deposits were formed, the connection of the mineralization with the earth-movements and the igneous activity being perfectly clear.

The most noteworthy feature of the mineralization is the high degree of alteration that the country rock has undergone. It appears that most, if not all, of the silica that now forms the great quartz veins was extracted by the mineralizing solutions from the older rocks, and replaced by carbonates and sulphides. Specially noteworthy is the formation of great masses of carbonate rock by replacement, the actual mineral being described as ankerite, a solid solution of the carbonates of lime, magnesia and iron in the dolomite group. Calcite is rare. Sericitic mica is abundant, and in the serpentines a characteristic product is the chromium-mica mariposite. The ankerite rock forms many important ore-bodies, in addition to the gold-bearing quartz veins.

The author states that the average yield of gold from all the ores now actually mined is about seven dollars per ton, which curiously enough is almost exactly the average figure for the Witwatersrand mines. Under present conditions the lower grade ores formerly worked are no longer profitable. Since however some of the deepest mines show an increasing amount of gold, it seems probable that this historic district may yet play an important part in the gold production of the world.

R. H. R.

GEOLOGIE UND RADIOAKTIVITÄT: Die Radioaktiven Vorgänge als Geologische Uhren und Geophysikalische Energiequellen. By GERARD KIRSCH. pp. viii + 214, figs. 48. Vienna and Berlin: Julius Springer. 1928.

AS a result of the brilliant pioneer work of Strutt and Joly, most of the early development of the now vigorous subject of radioactivity and geology was the work of British physicists and geologists. A good start was also made in the United States by Boltwood, but, possibly owing to the adverse influence of Becker, progress there remained at a standstill until Barrell drew attention to the significance of the British researches, and pointed out how ill-founded Becker's criticisms had been, despite their forcible and dogmatic tone. During the last decade American and Canadian workers have been particularly active, and those of Germany, Austria, Finland and Russia can also claim to have made notable contributions. Hitherto there has been no systematic treatise on the subject, apart from that branch of it dealing with the measurement of geological time. Dr. Kirsch, of Vienna, has now filled this gap in the literature with an excellent book that is not only a compilation of the work accomplished and the hypotheses discussed up to 1928, but is also itself a critical contribution of great interest, if not of permanent value. The latter qualification is inserted deliberately, because in trying to apply radioactive phenomena to the mechanism of processes within the earth we are still groping in the dark. Papers dealing with hypotheses are frankly put out for constructive discussion and criticism, and an inevitable weakness of any book that attempts to summarize the position is that it may unwittingly give a false appearance of stability to what are no more than temporary stepping-stones across dangerous rapids of speculation. The firm ground which undoubtedly awaits us on the further side has not yet been reached, and no book can yet be written which could reliably point the way to a safe crossing.

Kirsch's book deals with the principles of radioactivity; the distribution of the radioactive elements in rocks; radioactivity as a source of geological energy; and radioactive minerals as self-registering clocks. The above reflections apply, of course, to the third of these topics, Kirsch's treatment of which embodies a very full account of the three-cornered discussion that is in progress between Joly, Jeffreys and the reviewer. Curiously enough Kirsch finds what he regards as a weighty argument in favour of the existence of basaltic cycles in the numerous analyses of bröggerite from southern Norway that have now been made. When the lead-ratios are plotted in a frequency diagram the diagram reveals a number of peaks spaced at nearly equal distances. The range of the whole series covers a period of about 250 million years, while the time interval between adjacent groups is about 35 million years. Kirsch is greatly impressed by this apparent regularity, and argues that if secondary alterations had occurred in the bröggerites no such periodicity would have been detectable. He therefore thinks that each bröggerite has the lead-ratio appropriate to the date when it came into existence; that there were several periods of bröggerite crystallization; and that the particular one that corresponds to the injection of the pegmatite dykes cannot as yet be determined. Finally he deduces from the interval of 35 million years that the Frederikshald granite was magmatically reactivated over and over again, each period of excitation corresponding to a "Joly-Holmes basalt cycle". It appears to the reviewer that a very top-heavy superstructure has here been raised on extremely inadequate evidence. Statisticians will surely agree that the total number of observations —barely sixty—is far too small to justify the construction of a frequency curve with seven or eight peaks, to say nothing of a physical interpretation that involves the whole internal behaviour of the globe. Moreover, the form of the diagram depends on the interval selected. There is no doubt, however the interval be selected, that there are two peaks, at lead-ratios of 0·125 and 0·135. These are probably genuine, and it is not difficult to give a plausible explanation of a double period of granitization such as appears to be implied. The phenomenon is already clearly recognized in the syntectonic and apotectonic phases of igneous activity associated with the Caledonian orogenesis, and it has already been shown by many petrologists that certain pegmatites have had a far more complex history than had generally been suspected. Thus, although the correlation of Kirsch's hypothetical epochs of bröggerite formation with basaltic cycles is not likely to be accepted, the author's suggestion of a periodic excitation of magmatic and hydrothermal activity is likely to be a fruitful one in the interpretation of lead-ratios.

In calculating lead-ratios Kirsch uses the well-known formula $Pb/(U + k\ Th)$, but instead of adopting the value $k = 0{\cdot}38$, he uses $k = 0{\cdot}25$, a value derived from the analyses of certain thorianites. As there is evidence that the thorianites have been altered, their testimony is discredited at the source. Moreover, the recent work of Aston on the lead from bröggerite shows that if k differs from 0·38 it should be greater than this value rather than less. The value of k does not seriously affect the time-scale except when this depends on deductions from thorium minerals. Thus Kirsch gives higher ratios for the Devonian minerals of the Langesundfjord and for the Ceylon suite of thorites and thorianites than have hitherto been published. With an ingenious qualification he accepts the reviewer's hypothesis of the preferential leaching of lead from thorium minerals, and explains for the first time how it is that this process leads to nearly constant Pb/U ratios for the altered Langesundfjord minerals. It depends on a numerical coincidence in the distribution of lead and uranium in the crystal lattices that is just reached in minerals of Devonian age, but not in those of other ages.

The book is well printed and illustrated and has a particularly good bibliography of the subject. It may be purchased either bound or with paper covers, the former being well worth the extra cost.

Arthur Holmes.

APPLIED GEOPHYSICS IN THE SEARCH FOR MINERALS. By A. S. EVE and D. A. KEYS. pp. x + 253, with 92 figures. Cambridge University Press, 1929. Price 12*s*. 6*d*.

THE authors of this book, both of whom are professors at McGill University, Montreal, give an account, largely mathematical, of the different methods that are being applied at the present time in geophysical prospecting: even the divining rod is included, although this is not susceptible of mathematical treatment. This is not the place to discuss the value of such methods, though it is perhaps allowable to express a doubt whether some of them will eventually be found to justify the somewhat extravagant claims made for them by commercially interested parties. It is clear, however, that valuable results have already been attained in certain cases. The illustrations are clear and there is a useful bibliography.

THE PLATINUM DEPOSITS AND MINES OF SOUTH AFRICA. By P. A. WAGNER. pp. xv + 326, with 38 plates and 37 text-figures. Edinburgh: Oliver and Boyd. 1929. Price 21*s*.

ALTHOUGH the discovery of workable deposits of platinum in South Africa is comparatively recent, it seems clear that they constitute the greatest source of this metal so far known. At any rate this is the only country in which primary deposits are worked for platinum as the main product, although a certain amount is recovered as a subsidiary in the working of other metals elsewhere, as for example from the nickel ores of Sudbury, Ontario.

This book provides a comprehensive account of these extraordinarily interesting deposits, written authoritatively, with a first-hand knowledge of all the facts. The treatment is essentially scientific, with full descriptions of the petrology and mineralogy of the ores and of the rocks in which they occur, and a very valuable feature is a special chapter contributed by that well-known authority Dr. H. Schneiderhöhn, of Freiburg, on the mineragraphy and spectrography of the sulphidic platinum ores of the Bushveld complex, which are by far the most important. It is very regrettable that the strange occurrences of platinum in quartz in the Waterberg district which at one time attracted so much attention, and contained in places the highest percentages of the metal ever recorded, have turned out to be so patchy and erratic in their distribution as to be quite unworkable. Two or three picked specimens from the Elephant outcrop on Rietfontein and from Welgevonden actually assayed over 3,000 dwts. per ton, which is equivalent to about 0·5 per cent of the rock. But the low grade, though workable, ore of the Merensky horizon of the Bushveld norite occurs in illimitable quantities.

It is hardly too much to say that this occurrence is one of the most remarkable petrological and mineralogical phenomena ever described.

It is impossible here even to attempt to summarize its principal features. The full account here given must be read if its features are to be comprehended. In his preface Dr. Wagner states that he feels that sufficient credit has never been given to Dr. Hans Merensky for the part that he played in this epic of mineral exploration, not only in the location of the horizon itself over an enormous length of outcrop, but also in the discovery of the platinum deposits in dunite.

An account is also given of the platinum deposits connected with the Great Dyke in Rhodesia, and of the metals of the platinum group in the auriferous conglomerates of the Witwatersrand, which now produce important quantities of iridium and osmium. Dr. Wagner's description of the extremely interesting sulphide deposits of Insizwa and Tabankulu is not very encouraging so far as platinum prospects are concerned, since it appears that most of the supposed platinum is really palladium, and there is not very much even of that.

Both author and publishers are to be congratulated on the production of this beautifully printed and illustrated book, which is stated in the preface to have been produced hurriedly in spare hours snatched from a busy career: the reviewer can only say that it has not suffered thereby. At any rate, it must remain for a long time the final authority on its subject.

R. H. R.

[When this review was already in type, the Editor heard with the deepest regret the sad tidings of the untimely death of Dr. Wagner. This is a severe blow to geology in general and to South African geology in particular. The news will come as a special shock to those who took part in the Congress of 1929. An obituary will appear in due course.—16th December, 1929.]

GEOLOGISCHES WANDERBUCH DER WESTLICHEN DOLOMITEN. By MARIA M. OGILVIE GORDON. pp. xvi + 258, with 3 plates of fossils, 100 illustrations, and a coloured geological map. Vienna: G. Freytag and Berndt A. G., 1928.

THE geologist who visits the Western Dolomites and wishes to see something of the geology is singularly fortunate in having such a guide as this at his disposal. The name of the writer is sufficient guarantee of correctness, for a considerable part of our knowledge of the geology, and especially of the tectonics, is due to her own researches; but, in addition, the arrangement of the material and the thorough way in which the whole scheme of the book has been carried out, make it an admirable example of what a geological guide can be.

Three plates of characteristic fossils lie before the title-page facing towards the front cover. The arrangement is unusual, but will be approved by those who consult them in the field, especially if the wind is strong. The text begins with a general account of the stratigraphy and tectonics, occupying 61 pages. Then follow detailed descriptions of thirty-two excursions grouped in four series, which, together with an introductory sketch of the Dolomitenstrasse from Bozen to Cortina, fill 195 pages. Each description is prefaced by a brief statement of the approximate length, in hours or kilometres, of the excursion, and its main objects ; but what the visitor will most appreciate is the very clear way in which he is told what to look for as he goes along and the many excellent illustrations (photographs, sections, etc.) to help him.

A short bibliography closes the text. The map, which is in a tuck on the back cover, is the authoress's own map, on the scale of 1/25,000, of the Grödnertal and Fassatal area, and covers the ground of twelve of the excursions. Six more are included in another map which she has published in *Abhandl. Geol. Bundesanst. Wien*, vol. xxiv, H. 1 and 2, 1927 ; but unfortunately no extra copies were available for this guide.

In spite of the amount it contains, the book, with the map in its tuck, measures only $8\frac{1}{2} \times 5\frac{3}{8} \times \frac{7}{8}$ over all, including the convexity of the back, and its weight is just under 22 ounces.

P. L.

DANA'S MANUAL OF MINERALOGY. 14th edition. By W. E. FORD. New York. 1929. (London : Chapman and Hall, 20*s*. net.)

OF the Dana Mineralogies, the *Manual* first appeared in 1848 and after several revisions was entirely rewritten for the 13th edition in 1912. The present issue has been brought completely up to date by minor alterations and additions. Since acquaintance with the book in this country is not as wide as a total issue of 41,000 would suggest it merits, the most useful purpose of this review will be to compare its scope with that of the better-known *Text-book*. The aim throughout is to enable recognition to be made of minerals in hand-specimens only. Consistently with this, the crystallographic section describes in detail only the more important classes within each system. Section II on physical properties treats of hardness, specific gravity and so forth, whilst refraction and double refraction are dismissed in a few paragraphs. Section III is devoted to chemical mineralogy, whilst section IV, on descriptive mineralogy, occupies more than half the book, and is thoroughly comprehensive in its scope. Determinative tables form the concluding section, with an appendix on mineral statistics. To those for whom this lack of certain aspects is no disadvantage, " the elementary student, the mining engineer, the geologist, and practical man ", the *Manual* may be confidently recommended.

F. C. P.

COAL MEASURE PLANTS. By R. CROOKALL. pp. 80, with frontispiece and 39 plates. London: Edward Arnold & Co., 1929. Price 12*s*. 6*d*.

TWO hundred and forty of the commonest and most characteristic plants of the British Coal Measures are described and figured in this book. It is written as a practical guide to help the stratigraphical geologist and the amateur collector to identify their fossil plants; botanical details of structure, etc., are only briefly mentioned.

The first chapter is introductory and deals with the preservation of fossil plants, stratigraphy, nomenclature, and other general subjects. The next six chapters are devoted to brief descriptions of the species—each of which receives from five to ten lines in the text and a natural size drawing or photograph. The last chapter consists of lists of the species characteristic of each zone of the Coal Measures. There is also an appendix where advice is given on collecting fossil plants.

The whole book is very much condensed; the last chapter in particular would have been more valuable if it had been expanded so as to make it clearer which species are confined to one or two zones and which occur commonly in several.

Zoning of the coal seams by lamellibranches is not discussed.

A collector unacquainted with the Coal Measure plants should be able to determine most of his specimens correctly by means of this book. Sufficient of the more important references are given to enable him to proceed to a more critical identification of his specimens.

T. M. H.

REPORTS AND PROCEEDINGS.

LIVERPOOL GEOLOGICAL SOCIETY.

8th October, 1929.

Dr. E. Neaverson delivered the annual Presidential Address entitled: "The Lower Carboniferous rocks around Prestatyn, Dyserth and Newmarket (Flintshire)."

Reference was made to the general succession of faunas described last year (*Proc. Liverpool Geol. Soc.*, vol. xv, pt. 2, 1929). Various areas, where Carboniferous rocks protrude through the general covering of Drift, were then discussed in detail.

Moel Hirradug (south of Dyserth), and Marian Ffrith farther east, show red basement-beds (S_2–D_1) followed upwards by the *Composita* beds and *Palaeosmilia* beds of the D_1 subzone. The

Caninia beds (lower D_2) which appear at the north end of Moel Hirradug are displaced and truncated by faults. The *Chonetes* beds (upper D_2) extend through the high ground of Dyserth village to the reef-knoll of Craig Fawr, Meliden. The southern end of the Prestatyn hillside is formed of *Chonetes* beds, but north of Nant yr ogof the succession is repeated. At Prestatyn the D_3 beds are represented by dark limestones containing *Cyathaxonia* and other corals. Gop Hill near Newmarket shows excellent exposures of the *Chonetes* beds, while, further east, the Axton ridge is a continuation of the reef-knoll limestones.

Attention was focussed on the massive Chert formation which occupies an oval area from Voelnant to Llanasa. The structural features of these beds closely resemble those of the reef-knoll limestones, and in some intermediate localities bedded cherts are intercalated with calcite mudstones of the reef-knoll phase. It was suggested that deposition of the two facies was practically contemporaneous, and that precipitation of silica in the north and of calcareous mud in the south was accomplished under " reef-knoll " conditions.

The *Posidonomya* beds near Prestatyn were shown to be unconformable on the D_3 limestones. They were probably deposited in a channel between the limestone knolls and the chert knolls.

The fault-system of the district has two chief components, respectively peripheral and radial to the Flintshire plateau. The peripheral faults have displaced the radial dislocations, as also have faults of intermediate direction which join pairs of peripheral faults. The great peripheral Prestatyn fault which extends from the north-western flank of Moel Hirradug along the arcuate margin of the Prestatyn hillside is responsible for the most conspicuous topographical feature of the district.

MINERALOGICAL SOCIETY.

Anniversary Meeting, November 5th.

The following were elected officers and members of Council :—

President, Dr. G. T. Prior ; Vice-Presidents, Sir J. S. Flett, Dr. G. F. Herbert Smith ; Treasurer, Mr. F. N. Ashcroft ; General Secretary, Mr. W. Campbell Smith ; Foreign Secretary, Dr. J. W. Evans ; Editor of the Journal, Dr. L. J. Spencer ; Ordinary Members of Council, Mr. A. J. Bull, Prof. C. G. Cullis, Prof. H. Hilton, Dr. W. F. P. McLintock, Col. N. T. Belaiew, Mr. Harvey Collingridge, Mr. Henry Dewey, Prof. Arthur Holmes, Dr. A. Brammall, Mr. G. McDonald Davies, Prof. W. G. Fearnsides, Miss M. W. Porter.

Dr. C. E. Tilley : " On scawtite, a new mineral from Scawt Hill, Co. Antrim " (with chemical analysis by Mr. M. H. Hey).

This new monoclinic mineral, with composition $6CaO.4SiO_2.3CO_2$, occurs in the contact zone between the Chalk and Tertiary dolerite, from which another new mineral, larnite, was recently described (*Min. Mag.*, vol. xxii, p. 77).

Dr. F. Coles Phillips: "On the composition-plane of 010-twins in the acid plagioclases."

In the true pericline twin, the inclination of the variable composition-plane for different compositions is correctly given by Wülfing's curve. T. Barth's conclusion that there is no regular variation is not justifiable, and results partly from confusion with other twin-laws such as that of acline A. The pericline twin should be of frequent occurrence in the crystalline schists.

Mr. M. H. Hey: "On the variation of optical properties with chemical composition in the rhodonite-bustamite series."

A complete optical study of three analysed members of the rhodonite-bustamite series, together with the data available from the literature, shows regular variation in the optical properties and specific gravity with change in lime content.

Dr. F. Coles Phillips: "A preliminary account of some mineralogical and chemical changes induced by progressive metamorphism in the Green Bed group of the Scottish Dalradian."

Analyses prove the Green Beds to be a truly isochemical series in respect of the constituents significant in progressive metamorphism. The earliest-formed plagioclase is pure albite, but a progressive entry of the anorthite molecule can be traced. The adjustment to equilibrium is apparently close, all the reconstituted plagioclase of a given rock having the same composition. In the highest grades the felspar is a medium andesine. Similar variations with increasing grade are found in the associated epidiorites. The earliest-formed greenish micaceous mineral is shown to be a true potash mica, which undergoes increase in FeO in higher grades. Hornblende appears in the chlorite zone only in rocks low in potash.

Manchester Geological Association.

12*th November*, 1929.

W. Lloyd, B.Sc., and R. C. B. Jones, M.C., M.Sc.: "The Upper Carboniferous of Flintshire."

The area under consideration comprises the Holywell Shales and Coal Measures of 1-inch (N.S.) Sheet 108 (Flint) and part of 1-inch (N.S.) Sheet 96 (Liverpool).

The following zonal succession has been established in the Holywell Shales:—

	Holywell District.	*River Terrig.*	*Hope and Hawarden Area.*
Gastrioceras G.	*subcrenatum.*		
	Gwespyr Sandstone.	Gwespyr Sandstone.	Gwespyr Sandstone.
		cumbriense.	*cumbriense.*
	cancellatum.	*cancellatum.*	*cancellatum* & mut. γ.

	Holywell District.	*River Terrig.*	*Hope and Hawarden Area.*
Reticuloceras R.			*reticulatum* mut. γ.
	reticulatum mut. β.	*reticulatum* mut. β. sandstone.	*reticulatum* mut. β.
	reticulatum mut. α.		*reticulatum* mut. α & *E. ornatum.*
	reticulatum (type).		*reticulatum* (type).
	inconstans.		
Homoceras H.	*striolatum.*		*striolatum.*
	smithi.		sandstone.
	proteum & diadema.		
Eumorphoceras E.	*Anthracoceras glabrum.*	*H. nitidum.* *E. bisulcatum.*	*H. nitidum* and *E. bisulcatum.*
		barren shale.	
	P. corrugata cherts.	limestone.	coarse, pebbly grits.

In the south and east the Holywell Shales are unconformable on beds which are apparently of D_3 age. This is most marked at Nant-y-Figillt where *G. cancellatum* with *R. reticulatum* mut. γ were found a short distance above the limestone, the whole of the cherts and sandstones, together with the lower zones, being absent. At Holywell the unconformity is difficult to demonstrate and the *cf. pseudo-bilingue* and *cf. bisulcatum* zones of Mr. Sargent have not been found, but the presence of part of Zone E is indicated by the discovery of *A. glabrum.* From the lowest beds exposed, in a quarry 400 yards north-west of Holywell Workhouse, Dr. J. W. Jackson has identified a large form of *Posidonomya corrugata* Eth., a form identical with that which he finds low in the Edale Shales of Derbyshire. Specimens from this locality were formerly identified as *P. becheri* by Hind and Stobbs and by Mr. H. C. Sargent, an error which has led to much speculation as to the stratigraphical position of the cherts on which these beds rest.

The Coal Measures from above the Gwespyr Sandstone up to the Main or Five Yard Coal, which is succeeded by the same fauna as the Arley Mine, appear to represent the Lower Coal Measures of Lancashire and have a roughly similar thickness. No other fossils have been found in these beds and they show much more rapid variation than is the case in Lancashire.

The beds above the Main Coal correspond to the Middle Coal Measures of Lancashire, but are here much attenuated. This is probably due to thinning and not to unconformity, since the Buckley Fireclay Group at the top of the series appears to show changes indicative of the approach to Upper Coal Measures conditions.

GLASGOW GEOLOGICAL SOCIETY.

14*th November*, 1929.

A Contribution to the Geology of the Carboniferous Sediments of Kintyre. By William J. McCallien, B.Sc., and Robert B. Anderson.

Sediments of Carboniferous age occur in Kintyre in the district between Campbeltown and Machrihanish in three localities: (*a*) beneath the superficial deposits of the Laggan (*b*) in Torchoillean Burn, and (*c*) in Tirfergus Burn.

(*a*) In the Laggan the sediments form the Machrihanish Coalfield with which the authors deal in considerable detail. Mining operations have been carried out in Kintyre over a long period and the information obtained from underground workings and bores is incorporated by the authors in a six-inch map of the Carboniferous sediments. At present the workings at the colliery are suspended and an atmosphere of decay hangs over the pits.

The Machrihanish Coalfield is divided into two parts: Northern Area and Southern Area. No mining operations have been carried out in the Northern Area and the information on the strata in this part is obtained from three bore journals. Only one of these bores, that at East Machrihanish, proved the known coal seams of the Laggan. This bore was carried a few feet below the Main Coal and affords a valuable section of the strata above that horizon. Most is known about the Southern Area, in which the authors have mapped 8 coal seams. Of these the most important are the No. 3 Seam (Cannel Coal), the Kilkivan Coal, and the Main Coal. A fairly complete section of the strata of the coalfield is afforded by the shaft of the Argyll Colliery and by a bore put down from the Main Coal workings. The lowermost strata recorded are bauxitic clays and laterites.

(*b*) The Torchoillean Burn sediments consist chiefly of bauxitic and lateritic clays. Overlying the clays is a thin coal seam with sandstone on top.

(*c*) The best section of the Carboniferous sediments in Kintyre is that afforded by Tirfergus Glen. In this section an almost continuous series of exposures can be obtained from igneous conglomerates below through clays, shales, sandstones, coals, sandstones, and shales to the Main Limestone above.

The resemblance between the Ballycastle and Machrihanish Coalfields is shown to be remarkably striking. Both have been laid down on the north-western side of a pre-Carboniferous Highland Border ridge. This ridge was not of uniform height, but contained transverse valleys such as that through the Campbeltown district and that in the position of the present North Channel. Evidence is produced from Kintyre of the pre-Old Red Sandstone age of this ridge.

CORRESPONDENCE.

FOSSILS FROM VITI LEVU.

SIR,—In a paper by Dr. Matley and myself on Viti Levu, in the GEOLOGICAL MAGAZINE for 1927 (Vol. LXIV, pp. 65–75), I described a fossil as *Nodularia vitiensis*. I learn from Professor H. S. Ladd of the University of Virginia that he has obtained better material from the same beds, and the photographs and descriptions which he has very kindly sent me show clearly that the remains are those of marine, not freshwater, shells. I had considered the possibility of my specimens belonging to the Mactracea, but on the balance of evidence available decided in favour of the Naiadacea. Professor Ladd has now found a definitely mactroid hinge-line in a form which, if not identical with *vitiensis*, is very close to it. The palaeogeographical conclusions which I ventured to found on the occurrence of a *Nodularia* in Viti Levu consequently fall.

A. MORLEY DAVIES.

RAISED BEACHES IN LOCH TORRIDON AND LOCH ERRIBOL.

SIR,—In a recent number of the GEOLOGICAL MAGAZINE Mr. D. M. Reid says that he finds himself unable to agree with me that raised beaches occur in these two lochs, as stated on p. 321 of my contribution to the *Handbuch der Regionalen Geologie*. But for the compression necessary in a work of that character it would have appeared that my statement was a quotation from a paper by Mr. L. W. Hinxman (*Trans. Geol. Soc. of Edinb.*, vol. vi, pt. iv, p. 249) wherein the author says " at the head of Loch Torridon the 25 and 50 feet raised beaches form a plateau of considerable extent, the latter extending for more than a mile up Glen Torridon ". On p. 251 he says " at the head of Loch Erribol in North Sutherland, as has been pointed out by Sir Archibald Geikie [1] and as my friends and colleagues, Messrs. Peach and Horne, have shown by detailed mapping, similar phenomena occur, though in that locality satisfactory sections, such as those described above, are wanting."

I do not profess to adjudicate between Mr. Reid and the geologists who mapped the alleged beaches, but I venture to think that Mr. Reid might re-examine the evidence: it would be passing strange if Peach and Horne were wrong in the interpretation of their mapping.

PERCY F. KENDALL.

FRINTON, ESSEX.

A Correction.

Owing to absence abroad Dr. J. Parkinson was unable to see a proof of his letter in the December number on the Deinosaur beds of Tendaguru; the accidental omission of a word spoilt the meaning of one sentence. On p. 560, lines 20–1 should read: " brackish water conditions alternated with local *marine* episodes."

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[1] *Scenery of Scotland*, 2nd ed., 1887, p. 272.